ENGINEERING
DEPT.

INSTRUCTION MANUAL

Type 1656
Impedance Bridge

A

GENERAL RADIO

SER. NO. 601

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WARRANTY

We warrant that each new instrument manufactured and sold by us is free from defects in material and workmanship and that, properly used, it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, District Office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

Type 1656
Impedance Bridge

A

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Concord, Massachusetts, U.S.A. 01742
Form 1656-0100-A
September, 1970
ID-0100

Specifications

Range	Resolution (one digit on lowest range)	Accuracy*	
		Frequencies ≤1 kHz and small phase angle (fs = full scale)	Frequencies >1 kHz or large phase angle Typical additional error terms
Capacitance: 0.1 pF to 1100 μF Series or parallel, 7 ranges	0.1 pF	±(0.1% of reading + 0.01% of fs + 0.2% of reading on highest range)	$\pm(0.2\ Df_{kHz} + 0.5\ D^2 + 0.002\ f^2_{kHz})\%$
Inductance: 0.1 μH to 1100 μH Series or parallel, 7 ranges	0.1 μH	±(0.1% of reading + 0.01% of fs + 0.2% of reading on lowest range)	$\pm(0.2\ f_{kHz}/Q + 0.5/Q^2 + 0.002\ f^2_{kHz})\%$
Resistance: 0.1 mΩ to 1.1 MΩ Ac or dc, 7 ranges	0.1 mΩ	±(0.1% of reading + 0.01% of fs + 0.2% of reading on lowest range)**	$\pm(Qf_{kHz} + 0.003\ f^2_{kHz})\%$**
Conductance: 0.1 n℧ to 1.1℧ Ac or dc, 7 ranges	0.1 n℧	±(0.1% of reading + 0.01% of fs + 0.2% of reading on highest range)**	$\pm(Qf_{kHz} + 0.003\ f^2_{kHz})\%$**
Dissipation Factor, D: series capacitance **0 to 1**	. . .	±(0.001 ±5% of reading)	$\pm(0.001\ f_{kHz}$ + 5% of reading)
parallel capacitance **0.1 to 50**	. . .	±5% of reading (sliding null at high D)	± 5% of reading
Storage Factor, Q: series inductance **0.02 to 10**	. . .	±5% of reading (sliding null at low Q)	± 5% of reading
parallel inductance **1 to ∞**	. . .	±(5% of reading + 0.001) for 1/Q	$\pm(5\%$ of reading + $0.001\ f_{kHz})$ for 1/Q

* Full accuracy applies from 15 to 35°C, <85% RH (useful from 0 to 45°C). Residual terminal impedances of ≈0.3 pF, 0.15 μH, and 1 mΩ must be corrected to obtain specified accuracy.

** Terms apply to ac measurements when external phase balance is properly adjusted; otherwise accuracy is 0.5% of reading.

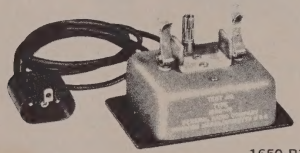
Generator: Internal, 1 kHz ±2% ac, 1.5 V dc. External, 20 Hz to 20 kHz ac; Type 1310 or 1311 Oscillator recommended.

Detector: Internal, 1 kHz ac with >20-dB rejection at 2nd harmonic or flat, meter indication; 10-μV/mm dc meter sensitivity. External, Type 1232 Tuned Amplifier and Null Detector recommended.

Bias: 600 V max on capacitors; small currents allowable on inductors and resistors; external only.

Terminals: ¾-in.-spaced binding posts for unknown; pin jacks for external ac generator and capacitor for ac phase balance; phone jacks for external detector, bias, and DQ adjustment.

Supplied: Batteries.

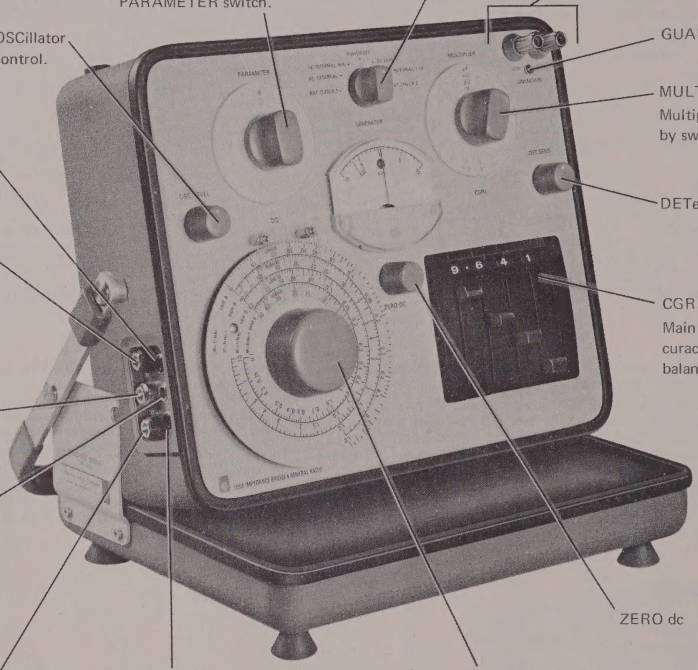


1650-P1 Test Jig

Available: 1650-P1 Test Jig for rapid and convenient connection of axial-lead components to bridge. Permits 3-terminal connection for negligible zero capacitance, introduces 80-mΩ total lead resistance (which only affects measurements on very low impedances), and adds a D or 1/Q error of less than 0.007.

Power: 5 D-cells, supplied; battery checks provided.

Mechanical: Flip-Tilt cabinet. *Dimensions* (w x h x d): Portable, 13¼ x 12⅞ x 6⅛ in. (337 x 327 x 170 mm); rack, 19 x 12¼ x 5¾ in. (483 x 311 x 146 mm). *Weight*: Portable, 14.5 lb (7 kg) net, 21 lb (10 kg) shipping; rack, 15.5 lb (7.5 kg) net, 28 lb (13 kg) shipping.



BIAS jack.

Voltage bias for capacitors: Apply bias only if PARAMETER switch is in C_s position. For C_p, refer to Section 2. Max voltage is 600 V dc. Add a resistor as a current limiter to prevent short circuit.

Current bias for inductors: Apply bias only if PARAMETER switch is in L_p position. For L_s, refer to Section 2.

GENERATOR switch.

Turns bridge on, selects internal or external generator, ac or dc, dc zero, checks batteries.

UNKNOWN terminals. Connect unknown impedance

PARAMETER switch.

Internal OSCillator LEVEL control.

GUARD connection.

MULTIPLIER switch.

Multiply CGRL decade setting by switch range for result.

DETector SENSitivity control.

OPP ARM jack.

Connect external decade capacitor for reactive balance of resistors.

CGRL decade:

Main balance control. For greatest accuracy, choose MULTIPLIER setting for balance between 1 and 10.

Ground.

DETector jack.

Useful to connect external amplifier or earphones for additional sensitivity or selectivity.

ZERO dc

DQ dial.

EXTernal DQ jack.

Useful for extending DQ range with a decade box.

EXTernal GENerator jack.

Max power: 0.05 W.

Max voltage: 500 V dc; or $\frac{f}{5}$ V ac rms where f is in Hz, or 100 V ac rms, whichever is smaller.

Frequency range for L and C: 20 Hz to 20 kHz.

Figure 1-1. Type 1656 Impedance Bridge.

Introduction—Section 1

1.1 DESCRIPTION 1-1
1.2 OPENING AND TILTING THE CABINET 1-1
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1.1 DESCRIPTION.

The Type 1656 Impedance Bridge (Figure 1-1) is a self-contained impedance-measuring system that includes six bridges for the measurement of capacitance, resistance, conductance and inductance as well as the generators and detectors necessary for dc and ac measurements. Features of this bridge include a basic 0.1% CGRL accuracy, high D and Q accuracy, convenient lever switches, visual ac and dc null indications, complete portability, and a convenient tilting mechanism and carrying case.

In the relay-rack model, the captive cover of the 1656 is replaced with a relay-rack adaptor panel.

1.2 OPENING AND TILTING THE CABINET.

The directions for opening the Type 1656 Impedance Bridge are given on the handle support of the instrument. Once open, the instrument can be tilted to any convenient angle. The angle should be chosen to give the most comfortable access to the knobs and the best view of the meter and dials.

The instrument may be locked fully open by the same slide pins that are used to lock the instrument closed. Thus, the instrument can be carried in the open position with the cover firmly in place.

Whether the instrument is open or closed, the cover forms a convenient storage place for the instruction manual and for any other test data that should be kept with the instrument.

1.3 POWER SUPPLY.

The 1656 is powered by five D cells. Four of the cells, which supply the ac oscillator and detector and the dc detector (BAT CHECK 1), slide into a fiber tube and should be installed with the positive terminals (center buttons) facing the open end of the tube. The fifth cell is the dc bridge supply (BAT CHECK 2) and is mounted in a spring clip. Its positive terminal should face the top of the instrument.

To install the batteries, proceed as follows.

a. Open the instrument cabinet and place it in the locked position.

b. Remove the two cabinet screws (Figure 1-4).

c. Lift the instrument from its cabinet.

d. Follow the directions on the battery tube.

e. Insert 4 batteries in the tube observing the correct polarity and place the battery tube back in its holder.

f. Slide the tip of a screwdriver in the slot between the clasp and the frame of the battery holder (see Figure 1-2) and lift the end of the screwdriver toward the top of the instrument. This should spring the clasp loose.

g. Insert battery with the positive terminal facing the top of the instrument, and reposition clasp by placing the end of the screwdriver through the clasp, catching the end of the frame and pushing the end of the screwdriver towards the bottom of the instrument.

h. Replace the instrument in its cabinet.

i. Replace the two cabinet screws.

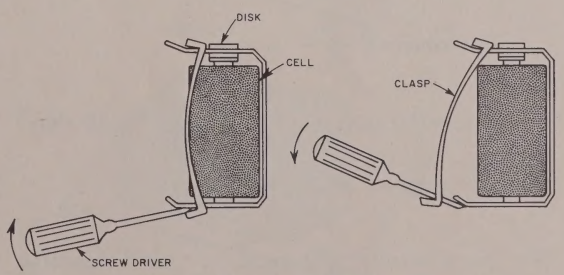

Figure 1-2. Battery removal and replacement.

1.4 SYMBOLS, ABBREVIATIONS, AND DEFINITIONS.

The following symbols, abbreviations, and definitions are used in this instruction manual:

C	capacitance (—|(—)
C_D	external decade capacitor
C_O	bridge residual capacitance
C_P	parallel capacitance
C_S	series capacitance
C_T	standard capacitor (0.1 μF)
C_X	unknown capacitance
G	conductance (—vvv—), the inverse of resistance
G_X	unknown conductance
L	inductance (—ɔɔɔ—)
L_O	bridge residual inductance
L_P	parallel inductance
L_S	series inductance
L_X	unknown inductance
R	resistance (—vvv—), the real part of an impedance
R_A	ratio arm resistance
R_B	standard 10 kΩ resistor
R_N	CGRL decade resistance
R_O	bridge residual resistance
R_P	parallel resistance
R_S	series resistance
R_T	DQ rheostat resistance
R_X	unknown resistance
X	series reactance, the imaginary part of an impedance
Z	impedance
Q	quality factor $= \frac{X}{R} = \frac{B}{G} = \frac{1}{D} = \tan\theta = \cot\delta$
	for inductors $\frac{\omega L_S}{R_S}$ or $\frac{R_P}{\omega L_p}$
D	dissipation factor $= \frac{R_S}{X} = \frac{G}{B} = \frac{1}{Q} = \cot\theta = \tan\delta$
	for capacitors $\omega C_S R_S$ or $\frac{1}{\omega C_P R_P}$
PF	power factor $= \frac{R_S}{\|Z\|} = \frac{R_S}{\sqrt{R_S^2 + X^2}} = \cos\theta = \frac{D}{\sqrt{1 + D^2}}$
f	frequency
ω	angular frequency, $2\pi f$
Ω	ohm, a unit of resistance, reactance, or impedance
kΩ	kilohm, 1 kΩ = 1000 ohms
M	multiplying factor applied to D and Q at frequencies other than 1 kHz
MΩ	megohm, 1 MΩ = 1 x 10^6 ohms
μF	microfarad, a unit of capacitance
mΩ	milliohm, 1mΩ = 1 x 10^{-3} ohm
nF	(or mμF) nanofarad (or millimicrofarad), 1nF = 1mμF = 1 x 10^{-3} μF
pF	(or $\mu\mu$F) picofarad (or micromicrofarad), 1pF = 1$\mu\mu$F = 1 x 10^{-6} μF
H	henry, a unit of inductance
mH	millihenry, 1mH = 1 x 10^{-3} H
μH	microhenry, 1 μH = 1 x 10^{-6} H
⏚	ground, case (chassis)
$\mho$	mho, a unit of conductance

1.5 SERIES AND PARALLEL COMPONENTS.

An impedance that is neither a pure reactance nor a pure resistance may be represented at any specific frequency by either a series or a parallel combination of resistance and reactance. Keeping this concept in mind will be invaluable for properly interpreting the bridge results. The values of resistance and reactance used in the equivalent circuit depend on whether a series or a parallel combination is used. The equivalent circuits are shown in Figure 1-3. A nomograph for series-parallel conversion at 1 kHz is given at the end of Section 3.

1.6 CGRL DECADE READINGS.

The main digital readout has eleven digits on each switch, 0 to 10. An X is used to indicate the 10 (to avoid the extra decimal place). All but the very highest readings can be obtained without using the X position (which is added mainly to facilitate the balancing procedure) so that it need not be used. However, a little practice in interpreting readings containing one or more X's will allow faster

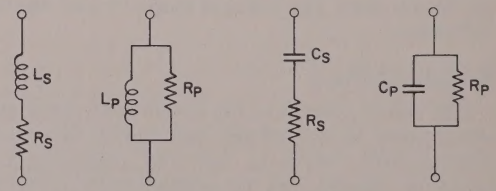

Figure 1-3. Equivalent circuits for complex impedance.

The relationships between the circuit elements are tabulated below. They are easily derived.

RESISTANCE AND INDUCTANCE

$$Z = R_s + j\omega L_s = \frac{j\omega L_p R_p}{R_p + j\omega L_p} = \frac{R_p + jQ^2\omega L_p}{1 + Q^2}$$

$$Q = \frac{1}{D} = \frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}$$

$$L_s = \frac{Q^2}{1 + Q^2} L_p = \frac{1}{1 + D^2} L_p$$

$$L_p = \frac{1 + Q^2}{Q^2} L_s = (1 + D^2) L_s$$

$$R_s = \frac{1}{1 + Q^2} R_p; \quad R_p = (1 + Q^2) R_s$$

$$R_s = \frac{\omega L_s}{Q}; \quad R_p = Q\omega L_p$$

RESISTANCE AND CAPACITANCE

$$Z = R_s + \frac{1}{j\omega C_s} = \frac{\frac{R_p}{j\omega C_p}}{R_p + \frac{1}{j\omega C_p}} = \frac{D^2 R_p + \frac{1}{j\omega C_p}}{1 + D^2}$$

$$D = \frac{1}{Q} = \omega R_s C_s = \frac{1}{\omega R_p C_p}$$

$$C_s = (1 + D^2) C_p; \quad C_p = \frac{1}{1 + D^2} C_s$$

$$R_s = \frac{D^2}{1 + D^2} R_p; \quad R_p = \frac{1 + D^2}{D^2} R_s$$

$$R_s = \frac{D}{\omega C_s}; \quad R_p = \frac{1}{\omega C_p D}$$

balancing, particularly with unknown values containing several zeroes. Some examples:

123X = 1240	1XXX = 2110
12X4 = 1304	XXXX = 11110
12XX = 1310	

1.7 PORTABLE-TO-RACK CONVERSION.

The following procedure is given so that a 1656 Bridge can be converted from a portable assembly to a rack-mounted assembly. To accomplish the mechanical and electrical changeover, a Rack Adaptor Set (P/N 1650-3370) must be ordered from General Radio.

To mount the instrument in a rack-adaptor panel, proceed as follows (Figure 1-4):

a. Open the instrument to its horizontal position (full open) and lock the handle.

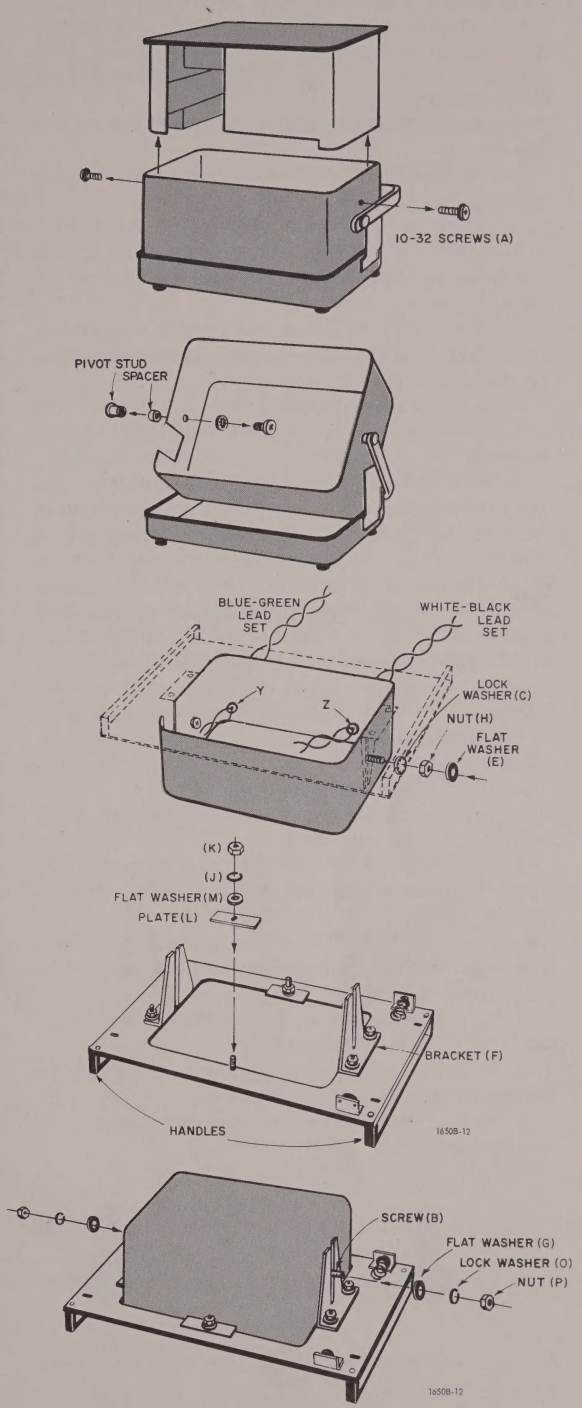

Figure 1-4. Rack mounting the 1656.

b. Remove the No. 10-32 screws (A) with resilient washers that hold the instrument in the cabinet. These screws are on the sides of the instrument (one per side) just above the handle pivot.

c. Lift the instrument out of the cabinet and set it to one side.

d. From the inside of the cabinet, remove the two pivot screws.

e. Lift the cabinet off the handle-and-cover assembly.

f. In place of the pivot screws, insert the two ¾-in. screws (B) supplied. Place the lockwasher (C) and nut (H) on each screw and secure.

g. Remove the eyelets from feet Y and Z in the cabinet.

h. Remove the rubber feet and install the supplied grommets (P/N 4110-0500).

i. Set the cabinet to one side.

j. Remove the battery tube (P/N 1650-1261) from the instrument by following the instructions on the tube.

k. Twist the white-black lead-set leads together and feed the unconnected ends through grommet Z in the cabinet from the outside to the inside. Twist the blue-green leads together and feed the unconnected ends through grommet Y.

l. Solder the white lead of the lead set to S103, 204R Figure 6-2). Solder the black lead to S102, 204R; the blue lead to S103, 205F; and the green lead to S103, 202R.

m. Install the instrument in its cabinet. Install and tighten the two No. 10-32 screws (A) removed in step b.

n. Loosen nut K on both sides of the opening in the rack panel and slide plate L toward the outside of the panel. Tighten nut K slightly so that L won't slide.

o. Put a large flatwasher (E) over the projecting screws on each side of the instrument.

p. Set the back of the instrument on a flat surface (face upward). Turn the instrument so that it is right side up as you look at it.

q. Lower the adaptor panel over the instrument being sure that the battery mounting brackets are on the right-hand side. Brackets F go over screws B.

r. Install a flat washer (G), lock washer (O) and nut (P) on screws B outside of bracket F.

s. Raise the adaptor panel up until it is flush with the instrument panel and rubber gasket.

t. Tighten nuts P and turn the instrument over onto the adaptor handles.

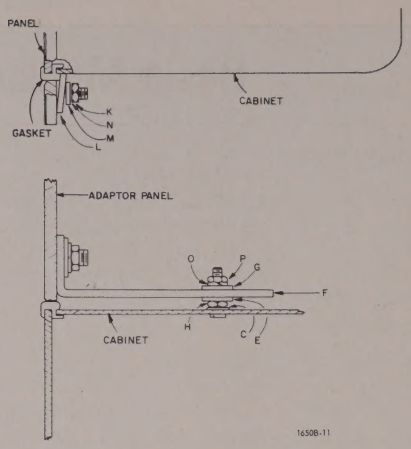

Figure 1-5. Detail view of panel mounting.

u. Loosen nuts K and slide plates L over the rubber gasket (Figure 1-5). Tighten nuts K.

v. Snap the battery tube and batteries into place between the insulators on the rack panel with the positive terminals pointing towards the top of the instrument. Snap the fifth battery into its clamp with its positive terminal pointing towards the top of the instrument.

1.8 CONNECTIONS.

The UNKNOWN terminals are standard ¾-in.-spaced binding posts that accept banana plugs, standard telephone tips, alligator clips, crocodile clips, spade terminals and all wire size up to number eleven (Figure 1-6).

The EXT DQ, DET, and BIAS jacks accept a two-terminal telephone plug such as the Switchcraft No. 440.

The EXT GEN, G, and OPP ARM jacks accept a single banana plug such as the GR Type 274-DB1 or -DB2 (P/N 0274-9730 or -9731). These jacks are spaced ¾-in. on centers so that a GR Type 274-MB Insulated Double Plug (P/N 0274-9746 can be used between the EXT GEN and G terminals or the OPP ARM and G terminals.

General Radio also makes a variety of interconnecting cables that can be used in various system interconnections. Some of these cables are shown in Table 2-3.

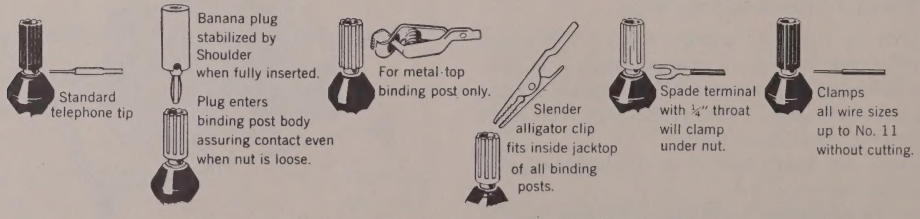
Standard telephone tip
Banana plug stabilized by Shoulder when fully inserted.
Plug enters binding post body assuring contact even when nut is loose.
For metal-top binding post only.
Slender alligator clip fits inside jacktop of all binding posts.
Spade terminal with ¼" throat will clamp under nut.
Clamps all wire sizes up to No. 11 without cutting.

Figure 1-6. Methods of connection to the measurement terminals.

Basic Measurements–Section 2

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2.3 EXTERNAL DC SUPPLY OR DETECTOR 2-5
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2.5 HIGH D AND LOW Q BALANCES 2-7

2.1 GENERAL.

Figure 2-1 shows the six bridge circuits used in the Type 1656 Impedance Bridge as well as the balance equation. Both Hay and Maxwell inductance bridges and series and parallel capacitance bridges are used to provide wide coverage on the D and Q ranges and to give both series and parallel values on the D range from 0.1 to 1 (Q from 1 to 10). For D values below 0.1 (Q above 10), the series and parallel values differ by less than 1%. Both resistance and conductance bridges are included to give a wide resistance range and to allow a choice of R or G between 1Ω and 1 MΩ. These two bridges can be used for ac or dc measurements, but for full accuracy an external capacitor is required for ac measurements (see paragraph 3.5).

The ac detector indicates signal magnitude and deflects only to the right. The dc detector deflects either to the right or left, depending on whether the unknown has a higher or lower value than that indicated by the range and adjustment settings.

A null is indicated by a zero (center) meter reading for both detectors.

The next two pages concisely state the information needed for making basic measurements using the internal sources and detectors. The schematics include all relevant bridge terminals to aid the user in making special measurements that require external sources, bias, etc. Symbols on the diagrams are the same as those defined in Section 1.

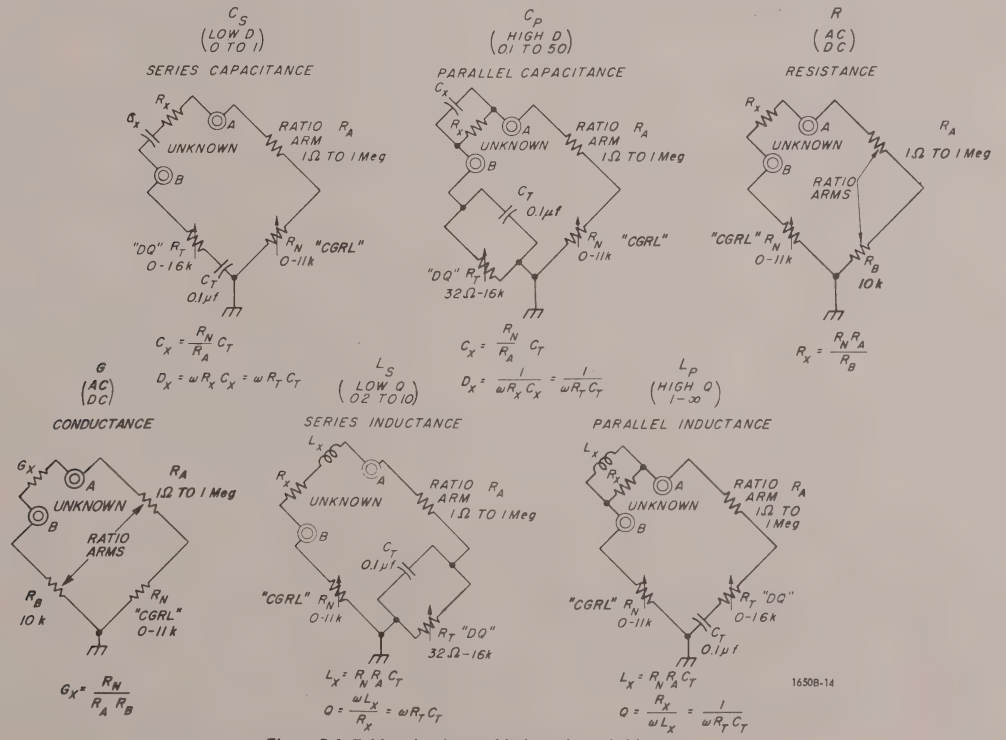
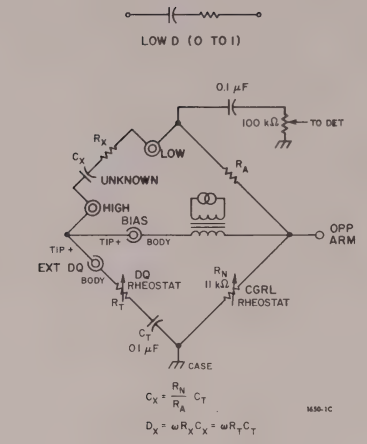


Figure 2-1. Bridge circuits used in impedance bridges.

C_S



	pF	nF			μF		
MULT	100	1	10	100	1	10	100
R_A Ω	1M	100k	10k	1k	100	10	1

a. Turn GENERATOR switch to BAT CHECK1 position. If the meter pointer is not in the BAT sector, replace the batteries in the tube.

b. Turn GENERATOR switch to AC INTERNAL 1 kHz.

c. Turn PARAMETER switch to C_S.

d. Connect the unknown so that most stray capacitance is between the LOW terminal and the case (see para. 3.8).

e. Turn OSC LEVEL full cw. The panel control affects only the internal oscillator.

f. Turn DQ dial full at cw.

g. Set the CGRL decade near 5000.

h. Adjust DET SENS for about 6 divisions deflection.

i. Turn MULTIPLIER switch for minimum meter reading.

j. Alternately adjust, first the CGRL decade, then the DQ dial for the best null, increasing the DET SENS as needed.

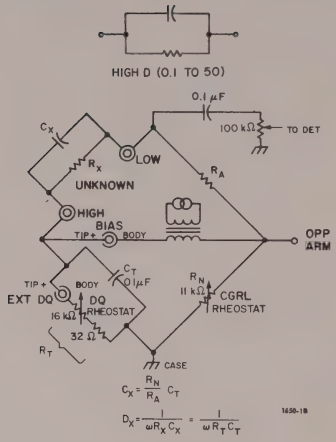
k. If the DQ dial goes into the uncalibrated portion, the unknown should be measured as C_p.

l. The series capacitance of the unknown equals the product of the CGRL-decade reading and the MULTIPLIER-switch setting.

m. The D of the unknown is the reading on the outer scale (Low D) of the DQ dial.

n. Turn GENERATOR switch to OFF.

C_P



	pF	nF			.. F		
MULT	100	1	10	100	1	10	100
R_A Ω	1M	100k	10k	1k	100	10	1

a. Turn GENERATOR switch to BAT CHECK1 position. If the meter pointer is not in the BAT sector, replace the batteries in the tube.

b. Turn GENERATOR switch to AC INTERNAL 1 kHz.

c. Turn PARAMETER switch to C_p. (Large electrolytics should be measured at a low frequency (120 Hz) for greater accuracy, (See para. 2.4).

d. Connect the unknown so that most stray capacitance is between the LOW terminal and the 1656 case (see para. 3.8).

e. Turn OSC LEVEL clockwise. The panel control affects only the internal oscillator.

f. Turn DQ full ccw.

g. Set the CGRL decade near 5000.

h. Adjust DET SENS for about 6 divisions deflection.

i. Turn MULTIPLIER switch for minimum meter reading.

j. Alternately adjust, first the DQ dial, then the CGRL decade for the best null, increasing the DET SENS as needed.

k. If D exceeds 1, adjustment procedure may become tedious, see para. 2.5.

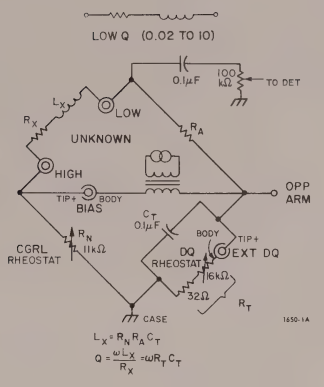
l. If the DQ dial reaches the stop at 0.1, the unknown should be measured as C_S.

m. The parallel capacitance of the unknown equals the product of the CGRL decade reading and the MULTIPLIER-switch setting.

n. The D of the unknown is the reading on the innermost scale (HIGH D) of the DQ dial.

o. Turn GENERATOR switch OFF.

L_S



	μH	mH			H		
MULT	100	1	10	100	1	10	100
RAΩ	1	10	100	1k	10k	100k	1M

a. Turn GENERATOR switch to BAT CHECK1. If the meter pointer isn't in the BAT sector, replace the batteries in the tube.

b. Turn GENERATOR switch to AC INTERNAL 1 kHz.

c. Turn PARAMETER switch to L_S.

d. Connect unknown so that most stray capacitance is between the LOW terminal and the case (see para. 3.8).

e. Turn OSC LEVEL cw. The panel control affects only the internal oscillator. Use full output except for nonlinear unknowns. Iron-core inductors are often nonlinear.

f. Turn DQ dial full cw.

g. Set CGRL decade near 5000.

h. Adjust DET SENS for about 6 divisions deflection.

i. Turn MULTIPLIER switch for minimum meter reading.

j. Alternately adjust the CGRL decade and DQ dial for the best null, DQ dial first, increasing the DET SENS as needed. Null means bring the pointer as near to the center of the meter as possible.

k. If Q is less than 1, the adjustment procedure may become tedious, see para. 2.5.

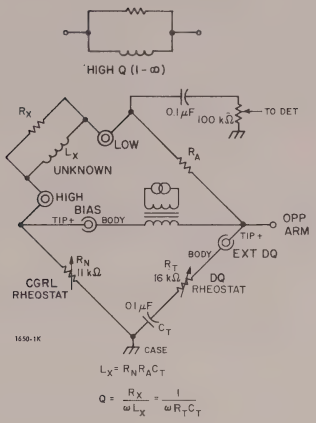
l. If a sharp null cannot be obtained and the Q dial is near 10, switch to L_P.

m. The series inductance of the unknown equals the product of the CGRL decade reading and the MULTIPLIER-switch setting.

n. The Q of the unknown is the reading of the third scale (LOW Q) of the DQ dial.

o. Turn GENERATOR switch OFF.

L_P



	μH	mH			H		
MULT	100	1	10	100	1	10	100
RAΩ	1	10	100	1k	10k	100k	1M

a. Turn GENERATOR switch to BAT CHECK1. If the meter pointer isn't in the BAT sector, replace the batteries in the tube.

b. Turn GENERATOR switch to AC INTERNAL 1 kHz.

c. Turn PARAMETER switch to L_P.

d. Connect unknown so that most stray capacitance is between the LOW terminal and the case.

e. Turn OSC LEVEL cw. The panel control affects only the internal oscillator. Use full output except for nonlinear unknowns. Iron-core inductors are often nonlinear.

f. Turn DQ dial fully cw.

g. Set CGRL decade near 5000.

h. Adjust DET SENS for about 6 divisions deflection.

i. Turn MULTIPLIER switch for minimum meter reading.

j. Alternately adjust the CGRL decade and DQ dial for the best null, CGRL first, increasing the DET SENS as needed. Null means bring the pointer as near to the center of the meter as possible.

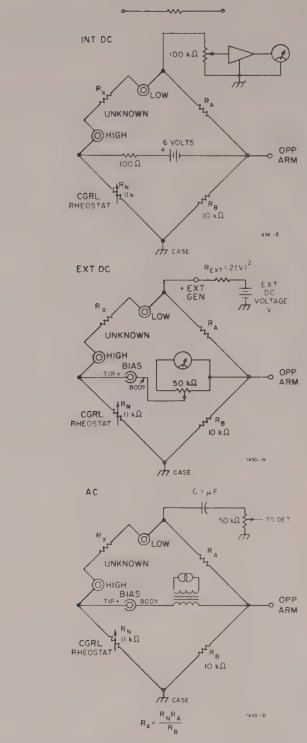
k. If a sharp null cannot be obtained, the unknown is too lossy and must be measured as L_S, or the unknown is not inductive.

l. The parallel inductance of the unknown equals the product of the CGRL decade reading and the MULTIPLIER-switch setting.

m. The Q of the unknown is reading of the second scale (HIGH Q) on the DQ dial.

n. Turn GENERATOR switch to OFF.

R



	mΩ	Ω			kΩ		
MULT	100	1	10	100	1	10	100
RAΩ	1	10	100	1k	10k	100k	1M

Dc Resistance.

a. Turn GENERATOR switch to BAT CHECK 1, then BAT CHECK 2, checking to see that the meter pointer indicates in BAT. sector. If the meter pointer in the first check is out of the BAT sector, replace the 4 cells in the tube; if second check is out of the BAT sector, replace the separate cell in the clamp (see para. 1.3).

b. Turn GENERATOR switch to DC INTERNAL and parameter switch to R.

c. Set CGRL decade to full scale, XXXX.

d. Set DET SENS control at mid range (spot up).

e. Turn MULTIPLIER switch full ccw. Then rotate cw one position at a time until the meter deflection reverses direction.

f. Adjust CGRL decade for best zero (center) deflection, increasing DET SENS if necessary.

g. Set GENERATOR switch to DC ZERO and adjust ZERO DC knob for new meter reading.

h. Set GENERATOR switch to DC INTERNAL and repeat balance of main reading.

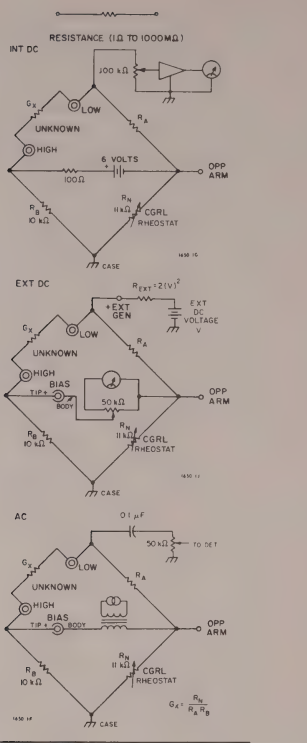
i. The unknown resistance is the reading of the CGRL readout multiplied by the MULTIPLIER switch setting.

j. Turn GENERATOR switch to OFF.

Ac Resistance.

The balancing procedure for the AC resistance is similar to that for C or L except that the R parameter switch portion is used and there is no DQ adjustment (see also para. 3.5).

G



	n℧	μ℧			m℧		
MULT	100	1	10	100	1	10	100
RAΩ	1M	100k	10k	1k	100	10	1

Dc Conductance.

a. Turn GENERATOR switch to BAT CHECK 1, then BAT CHECK 2, checking to see that the meter pointer indicates in BAT sector. If the meter pointer in the first check is out of the BAT sector, replace the 4 cells in the tube; if second check is out of the BAT sector, replace the separate cell in the clamp. (see para. 1.3.)

b. Turn GENERATOR switch to DC INTERNAL and parameter switch to G.

c. Set CGRL decade to full scale, XXXX.

d. Set DET SENS control at mid range (spot up).

e. Turn MULTIPLIER switch full ccw. Then rotate cw one position at a time until the meter deflection reverses direction.

f. Adjust CGRL decade for best zero (center) deflection, increasing DET SENS if necessary.

g. Set GENERATOR switch to DC ZERO and adjust ZERO DC knob for new meter reading.

h. Set GENERATOR switch to DC INTERNAL and repeat balance of main decade.

i. The unknown conductance is the reading of the CGRL readout multiplied by the MULTIPLIER switch setting.

j. Turn GENERATOR switch to OFF.

Ac Conductance.

The balancing procedure for the ac conductance is similar to that for C or L except that G parameter switch portion is used and there is no DQ adjustment (see also para. 3.5).

2.2 SENSITIVITY AND APPLIED POWER.

With the internal 1.5-Vdc supply, there should be sufficient sensitivity for any dc resistance or conductance measurement. This supply current is limited with a 15-Ω resistance to 100 mA, and gives a maximum possible applied power of .0375 W, so that there is no danger of damaging components with ratings of .05 W or more. If more sensitivity is required, or if a higher or lower applied power is required, see para. 2.3.

The ac oscillator and detector system is also adequate for all ranges as long as the OSC LEVEL is fully cw. The oscillator delivers a maximum of approximately 0.3 V rms and gives a maximum possible applied power of approximately 2 mW. This low voltage level and applied power is safe for almost all components, and only a small bias voltage is required to keep the voltage from reversing for measurements in polarized components. Nonlinear devices, such as iron-cored inductors, may change value as the level is changed. If the low-level value is desired, the OSC LEVEL should be reduced until the measured value remains constant.

Increased sensitivity may be obtained by using an external oscillator or detector, and measurements at other than 1 kHz require an external generator (see para. 2.4).

2.3 EXTERNAL DC SUPPLY OR DETECTOR.

An external dc supply may be used to apply a higher or lower voltage to the unknown or to obtain increased sensitivity. The voltage should be applied between the HIGH UNKNOWN terminal and the OPP ARM jack (on the side of the instrument). The GENERATOR switch should be set to DC ZERO for the measurement, and the zero adjustment should be made with the external source disconnected.

The external supply should be current limited so that it can deliver a maximum of 0.5 W and to avoid damage to the bridge. This is most easily accomplished by placing a resistor with a resistance of $E^2/2$ Ω (where E is the supply voltage) in series with the source. For low-resistance measurements a low voltage and a low resistance will supply the most power to the unknown resistor and give the best sensitivity. For high resistance values, the maximum power is obtained from a high-voltage supply limited to 7 mA, to protect the standard resistor, but unless the utmost voltage is required, a 100-V supply, with a 25-kΩ resistor in series, is recommended for operator safety.

WARNING

Bridge voltages must be limited to protect the bridge and the unknown component from damage. It is also advisable to limit the current to 5 mA or less to protect the operator from injury. The maximum applied voltage (E_A) limits and the corresponding voltages across the UNKNOWN terminals (E_x) are given in Table 2-1.

The internally supplied dc voltages across the UNKNOWN terminals for CGRL decade settings of 1.000 and 10.000 for each of the ranges of the R bridge are given in Table 2-1.

Table 2-1

DC VOLTAGE ACROSS UNKNOWN

Range MUL	DECADE SETTING 1.000	10.000
100 mΩ	0.01 V	0.09 V
1 Ω	0.06 V	0.42 V
10 Ω	0.12 V	0.70 V
100 Ω	0.14 V	0.75 V
1 kΩ	0.14 V	0.75 V
10 kΩ	0.14 V	0.75 V
100 kΩ	0.14 V	0.75 V

Table 2-2

MAXIMUM DC BRIDGE VOLTAGE

Range Multiplier	Decade setting of 1.000		Decade setting of 10.000	
	E_A	E_X	E_A	E_X
100 mΩ	0.77 V	0.07 V	1.4 V	0.7 V
1 Ω	2.4 V	0.22 V	4.4 V	2.2 V
10 Ω	7.7 V	0.70 V	14 V	7.0 V
100 Ω	24 V	2.2 V	44 V	22 V
1 kΩ	77 V	7.0 V	140 V	70 V
10 kΩ	77 V	7.0 V	140 V	70 V
100 kΩ	77 V	7.0 V	140 V	70 V

A maximum value of E_A and E_X for settings between 1.000 and 10.000 can be calculated by interpolating between the values in Table 2-2. Letting the value of E_X at a decade setting other than 1.000 or 10.000 on some specific range be E_X', and the value of E_X at the decade setting of 10.000 on the same range be E_{X10}, then

$$E_X' = \frac{\text{decade setting}}{10} \times E_{X10}$$

The value of E_A at the same decade setting, E_A', may be calculated by

$$E_A' = \left(\frac{\text{decade setting}}{10} + 1\right) E_{X10}$$

For the G bridge, the voltage across the unknown may be 70 V on any of the lower three G ranges independent of the CGRL decade setting. The maximum applied bridge voltage, E_A, varies from 77 to 140 V as the decade is set between 1.000 and 10.000 (X.000).

An external dc detector can be used if desired. It should be connected between the LOW UNKNOWN terminal and case (the screw beneath the UNKNOWN terminal). Unless disconnected internally, the internal detector will still be functioning and will shunt the external detector input with approximately 100 kΩ.

2.4 MEASUREMENTS AT OTHER FREQUENCIES.

2.4.1 General.

An external ac supply is necessary to make measurements at frequencies other than 1 kHz or to obtain higher signal levels at 1 kHz. The normal frequency range is 20 Hz to 20 kHz but satisfactory operation to 100 kHz is possible under certain conditions (see paragraph 4.11). Typical accuracy at other frequencies is given in the specifications, and other considerations are discussed in Section 4.

When an external generator is used, the GENERATOR switch should be set to AC EXTERNAL. In this position the detector is untuned, but generally satisfactory as long as the unknown is linear and excessive hum or other pickup is not present. A tuned detector (GR 1232 recommended) may be connected to the DET jack to give selectivity or additional sensitivity if required.

2.4.2 Connection of External Generator.

In most cases when an external generator is used it should be connected to the EXT GEN jack on the side of the bridge. In this connection, the external generator is connected directly to the internal bridge transformer when the function switch is in the AC EXTERNAL position, and the low generator terminal is connected to the bridge chassis (which should be grounded; paragraph 4.6). A second ground connection to the generator should be avoided.

If the external generator can be overdriven when connected to a low-impedance load, it is generally desirable to place a resistor in series with the ungrounded generator connection to the bridge. This resistor should be large enough to prevent distortion even when the bridge input is short-circuited. The bridge input impedance at the EXT GEN jack is a minimum of 200 Ω (resistive) at 1 kHz when the bridge is set to measure a short circuit on the UNKNOWN terminals. This is shunted by the inductance of a primary of the bridge transformer, which is approximately 1 H.

In some cases where more input power is required, particularly in measurements of low impedance, a matching transformer between generator and bridge is useful. This transformer need not be shielded. The GR Type 1311 Audio Oscillator is recommended for this application at frequencies of 50, 60, 100, 120, 400, 500, 1000, 2000, 5000, and 10,000 Hz because its output will not be distorted by over-loading and it has a matching transformer to drive low-impedance loads.

When the desired bridge voltage is higher than can be applied by the internal bridge transformer, the generator can be connected directly in the bridge circuit by connection to the BIAS jack (Figure 2-2a). In this connection, the generator is ungrounded and capacitance from its terminals to ground must be considered. Capacitance from the negative BIAS terminal to ground can cause a large error at high frequencies when low impedances are measured. Therefore, use a shielded cable and use the outer conductor to connect the low generator terminal to the positive BIAS terminal. Capacitance of over 100 pF from the positive BIAS terminal to ground can cause appreciable error (paragraph 4.6). A bridge transformer can be used to connect a generator to the BIAS jack, but this has no advantage over the use of the internal bridge transformer unless the external transformer has a higher voltage rating.

2.4.3 Maximum Applied Ac Voltage.

The maximum ac voltage that may be applied to the 1656 Impedance Bridge depends on:

a. the voltage and power ratings of each component (including the unknown),

b. the bridge circuit used,

c. the range used,

d. the position of the variable components,

e. the method of applying the voltage.

Exact limits for any specific measurement can be calculated from the circuit diagrams of Figure 2-1, and by insuring

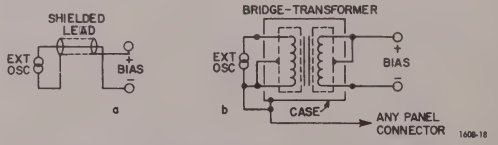


Figure 2-2. Methods of applying external ac.

that the power dissipation in the bridge resistors is less than 0.5 W. If such a maximum voltage is applied, care must be taken to avoid any adjustments of the panel controls that would result in an overload.

A much simpler approach is to limit the power into the bridge to 0.5 W so that no bridge components can be damaged under any conditions. If the power rating of the unknown is less than 0.5 W, the input power should be reduced accordingly. A series resistor is the simplest way to limit the power. It should have a value of $R = E^2/4P$, where E is the open-circuit generator voltage and P the power rating of the unknown component.

The input transformer imposes the following further limit on the voltage applied to the EXT GEN jack:

$$E_{max} = \frac{f}{2.5} \text{ V (f in Hz), or 100 V,}$$

whichever is smaller. This transformer has a 10 to 1 step-down ratio and an equivalent resistance, referred to the primary, of 100 Ω. Therefore, to limit the power applied to the bridge to 0.5 W, a series resistor of $E^2/2 - 100\ \Omega$ should be placed in series with the external supply.

2.5 HIGH D AND LOW Q BALANCES.

When the D of a capacitor is larger than 1, or the Q of an inductor is less than 1, the component is really more resistive than reactive. When these components are measured as capacitors or inductors, or a bridge reading C and D (or L and Q), the two adjustments are interacting so that many successive adjustments are required to obtain a balance.[1] The high D loss term in the specifications, 0.5 D^2%, is included mainly to warn the user of this difficulty. With patience much better accuracy is possible, in the order of 0.1D% on the C_p and L_s bridges.

While a straightforward balancing procedure of alternate C and D (or L and Q) balances is satisfactory up to D values of unity (down to Q values of unity) covered by the C_s (and L_p) bridges, a slightly different procedure is preferable for very high D values (very low Q values) as covered by the C_p and L_s bridges.

a. Start with the CGRL decade set to XXXX.

b. Balance the DQ dial first.

c. Adjust the first CGRL digit for best null.

d. Readjust the DQ dial.

e. Step the first CGRL lever down one digit at a time, making continual DQ adjustments. Stop when the best null is read.

f. Repeat the same procedure with the second, third, and fourth levers, in that order.

For extremely high D values or low Q values it may be preferable to measure the unknown as a resistor (R measurements, paragraph 2.1). This is of course necessary if the D or Q range is exceeded. It will also give a more accurate measurement of the resistive part of the impedance which is the dominating part, but a poorer measure of the reactive part. However, the balance convergence will be much faster.

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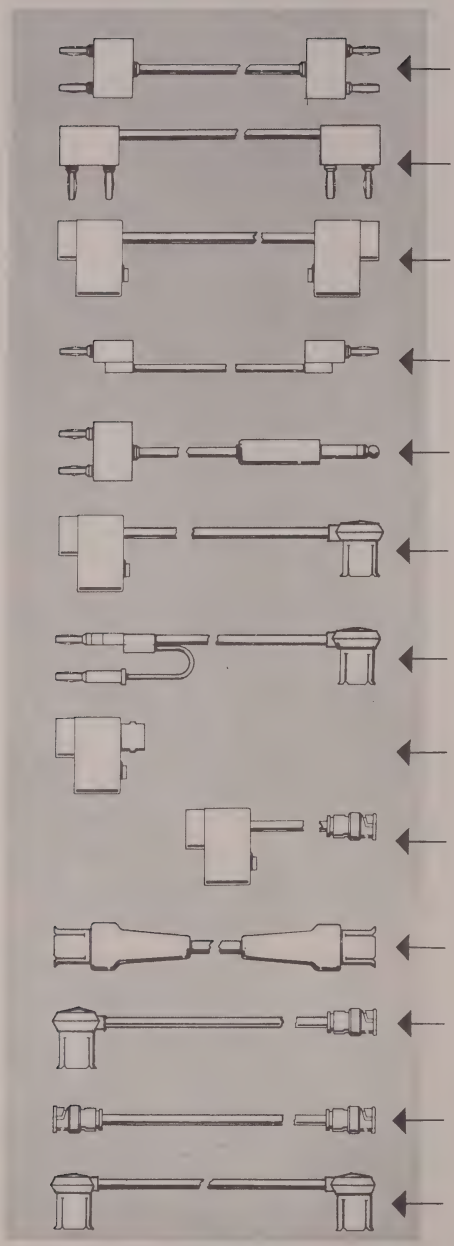
[1] Hall, H. P., "Orthonull - A Mechanical Device To Improve Bridge Balance Convergence", General Radio *Experimenter* Vol. 33, No. 4 (April, 1959).

Table 2-3

AVAILABLE INTERCONNECTION ACCESSORIES



TYPE NO.	DESCRIPTION	CATALOG NO.
274-NQ	Double-plug patch cord, in-line 36" long	0274-9860
274-NQM	Double-plug patch cord, in-line 24" long	0274-9896
274-NQS	Double-plug patch cord, in-line 12" long	0274-9861
274-NP	Double-plug patch cord, right-angle 36" long	0274-9880
274-NPM	Double-plug patch cord, right-angle 24" long	0274-9892
274-NPS	Double-plug patch cord, right-angle 12" long	0274-9852
274-NL	Shielded double-plug patch cord, 36" long	0274-9883
274-NLM	Shielded double-plug patch cord, 24" long	0274-9882
274-NLS	Shielded double-plug patch cord, 12" long	0274-9862
274-LLB	Single-plug patch cord, black, 36" long	0274-9468
274-LLR	Single-plug patch cord, red, 36" long	0274-9492
274-LMB	Single-plug patch cord, black, 24" long	0274-9847
274-LMR	Single-plug patch cord, red, 24" long	0274-9848
274-LSB	Single-plug patch cord, black, 12" long	0274-9849
274-LSR	Single-plug patch cord, red, 12" long	0274-9850
1560-P95	Adaptor cable, double-plug to telephone plug, 36"	1560-9695
874-R34	Coaxial patch cord, double plug to GR874, 36" long	0874-9692
874-R33	Coaxial patch cord, two plugs to GR874, 36" long	0874-9690
274-QBJ	Adaptor, shielded double plug to BNC jack	0274-9884
776-A	Patch cord, shielded double plug to BNC plug, 36" long	0776-9701
874-R22A	Coaxial patch cord GR874 to GR874, 36" long	0874-9682
776-B	Patch cord, GR874 (right-angle) to BNC plug, 36" long	0776-9702
776-C	Patch cord, BNC plug to BNC plug, 36" long	0776-9703
776-D	GR874 to GR874, both right-angle, 36" long	0776-9704

274-13XA

Special Measurements—Section 3

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3.1 GENERAL.

The inclusion of the EXT DQ, BIAS, and OPP ARM jacks in the 1656 permits many special measurements to be made. The EXT DQ jack allows extension of the DQ coverage at frequencies below 100 Hz, the BIAS jack allows a bias voltage or current to be applied across or through an unknown impedance, and the OPP ARM jack allows more accurate balancing of reactive resistors. The following section presents a few of the many applications possible with these external connection jacks.

3.2 APPLICATION OF DC BIAS TO CAPACITORS.

3.2.1 Internal Oscillator Operation.

Up to 600 V of dc bias may be applied to the unknown capacitor by any of several different methods. The simplest method can be used for measuring only series capacitance; fortunately, this is how most capacitors are specified.

WARNING

Charged capacitors form a shock hazard, and care should be taken to ensure personal safety during measurement and to be sure that the capacitors are discharged after measurement. The external dc supply should also be handled carefully.

It is advisable to limit the power that may be drawn from the external dc supply to 0.5 W (by a resistor, fuse, or circuit breaker) in order to protect the bridge components in case the unknown is short-circuited.

The various methods of applying dc bias to capacitors and suggestions for their use are described in the three methods that follow:

Method 1. C_s Bridge (Figure 3-1a).

In this method, up to 600 V may be applied on any range. Connect the negative terminal of the unknown capacitor (if polarized) to the LOW UNKNOWN terminal. The dc supply used should have a low ac output impedance. It is usually helpful to ground the negative side of the dc supply and to leave the bridge floating to avoid hum from the power line. If the negative side of the supply (BIAS jack body) is grounded, the bridge panel and LOW UNKNOWN terminal will be at low dc potential with low signal voltage on them.

Method 2. C_p Bridge (Figure 3-1b).

The same precautions mentioned in Method 1 apply here, and a blocking capacitor should be added using the EXT DQ jack. The positive side of the blocking capacitor should be tied to the tip of the phone plug. The voltage rating of this capacitor should be sufficient for the full dc applied and its value should be much larger than 0.1 μF. The capacitance required depends on the D of the unknown and on the accuracy required. The errors caused by this capacitor are:

$$C_x = C_m + \frac{C_m C_t}{C_b} D_m^2 \qquad \text{where } C_t = 0.1\ \mu F$$

$$D_x = D_m - D_m^3 \frac{C_t}{C_b} \qquad \text{and } C_b >> C_t$$

where C_m and D_m are the measured values. The correction terms should be calculated and added to the measured values as indicated above.

Method 3. C_s or C_p Bridge (Figure 3-1c and e).

This method is recommended for small capacitors. The maximum voltages that may be applied to the C_s and C_p

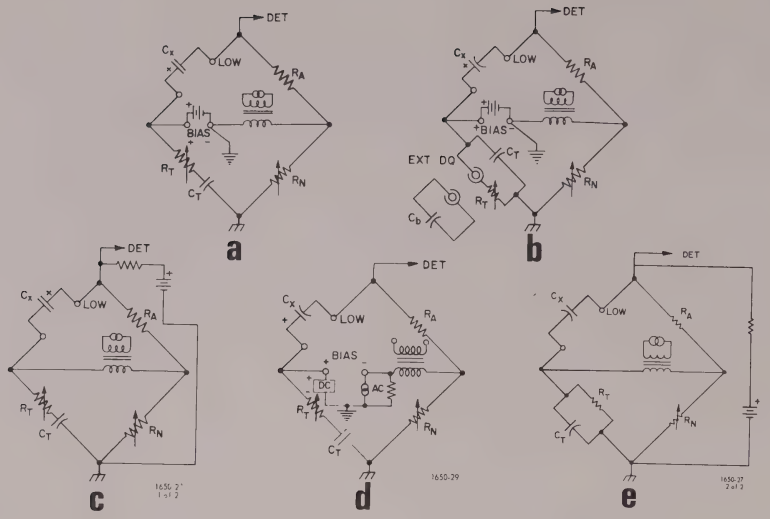

Figure 3-1. Methods of applying dc voltages to capacitance.

bridge are given in Table 3-1, but the maximum voltage on the bridge are a function of the CGRL-and-DQ-dial settings.

The ac impedance of the dc source should be high (>10 kΩ) to avoid shunting the detector, and the dc source should have low hum. The advantages of this circuit are that the bridge and supply are both grounded and the dc current can be easily limited by a resistor, since the impedance of the source should be high.

WARNING

Note that the LOW UNKNOWN terminal has the high voltage on it in this method.

3.2.2 External Ac Generator Operation.

When both external ac and dc supplies are used, hum may be introduced by the capacitance to the line in the power transformers of these generators. The bridge should be set up as shown in Figure 3-1d, with both the ac and dc supplies grounded and the bridge not grounded. The ac generator should be shunted by a resistor if it does not provide a path for dc.

Method 3, paragraph 3.2.1, may also be used to apply dc bias. The bridge and both the ac and dc supplies are grounded (Figure 3-1), and the ac generator is connected to the EXT GEN jacks. This method is particularly useful for high-frequency measurements of small capacitors (paragraphs 2.4 and 3.2.1).

Table 3-1

MAXIMUM DC VOLTAGES APPLIED TO CAPACITORS BY METHOD 3

Range Multiplier	Max Volts On Bridge	Max Volts On Unknown
100 pF	505 V	500 V
1 nF	242 V	220 V
10 nF	142 V	71 V
100 nF	78 V	7 V
1 μF	72 V	0.7 V
10 μF	71 V	0.07 V
100 μF	71 V	0.007 V

3.3 APPLICATION OF DC TO INDUCTORS.

Direct current may be supplied to inductors during measurement by any of several different methods so that incremental inductance measurements may be made. The various methods are described below along with suggestions for their use. An external blocking capacitor (C_b in Figure 3-2b and -2c) is needed only for the L_s bridge shown. It should be connected by a phone plug inserted into the EXT DQ jack. The errors caused by this capacitor are:

$$L_x = L_m + \frac{C_t}{C_b}\frac{L_m}{Q_m^2} \qquad \text{where } C_t = 0.1\ \mu F$$

$$Q_x = Q_m + \frac{C_t}{C_b}\frac{1}{Q_m} \qquad \text{and } C_b >> C_t$$

where L_m and Q_m are the measured values. The correction terms should be calculated and added to the measured values as indicated above.

WARNING

Large inductors carrying high currents are shock hazards. Reduce the dc to zero before disconnecting the dc supply or unknown inductor.

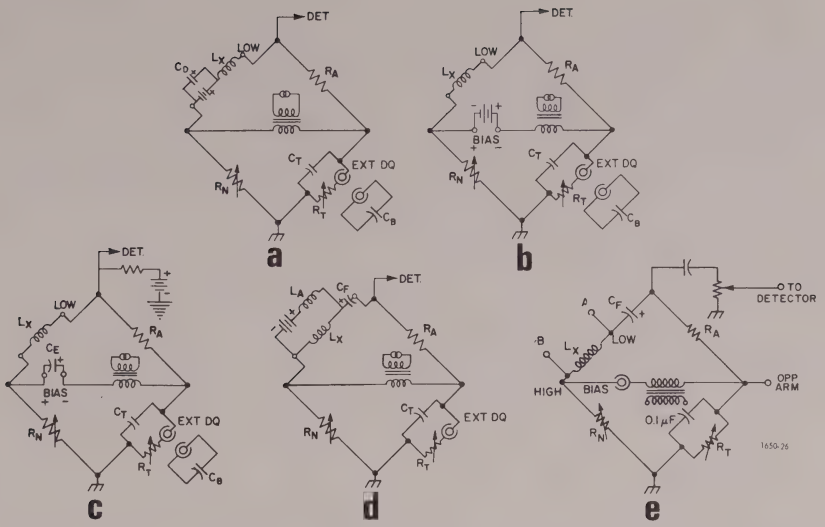

Figure 3-2. Methods of applying dc to inductors. (Blocking capacitor C_B is not supplied with the bridge.)

Method 1. (Figure 3-2a.)

The maximum current is limited to that given in Table 3-2. The dc supply may be tied to ground and the instrument left floating as shown, where the capacitance of the bridge to ground shunts R_n and causes a D (1/Q) error of $-\omega R_n C$. If the dc supply has low internal capacitive coupling to the power line, the bridge may be grounded and the dc supply left floating.

The source impedance of the dc supply must be low compared with that of the unknown, since the bridge measures both of these impedances in series. A large capacitor (C_D) shunting the dc supply is sometimes useful.

Method 2. (Figure 3-2b.)

The maximum current in this method is limited to that given in Table 3-2. The dc supply is connected to the BIAS jack with the signs reversed in order to keep the bridge case and dc supply both at zero volts dc from ground. The blocking capacitor C_B must be able to take the full dc voltage. The ground connection may be made to either the panel or the dc supply.

Method 3. (Figure 3-2c.)

This method is recommended for large inductors, since the maximum current is the same for any range. In this method both the bridge and the dc supply are grounded.

The maximum allowable current for any range is 7 mA. The output impedance of the dc supply should be high enough to avoid loading the detector (a series resistor is often useful) and should have low hum.

The blocking capacitor C_E must be able to take the dc IR drop across the unknown inductor, and C_B must be able to take the whole dc voltage.

Method 4. (Figure 3-2d.)

This method must be used with very large dc. The maximum voltage on the unknown is limited only by the rating of C_F. The ac source impedance of the dc supply must be much higher than the impedance of the unknown since the bridge measures the parallel combination of these two impedances. A large inductor, L_A, may be connected as shown to provide a high source impedance. Often it is possible to resonate the feed inductor to increase the source impedance further. Also, the impedance of the blocking capacitor, C_F, should be low compared with the impedance of the unknown since it is directly in series with the unknown. The blocking capacitor, C_B, is not needed for this method and can be shorted out or removed.

Method 5. (See Figure 3-2e.)

This method permits large or small dc currents by connecting a current source in parallel with the unknown inductor. The dc voltage is isolated from the bridge by capacitor C_F. The impedance of C_F should be low compared to the unknown since they are in series. The current source impedance must be high relative to the unknown at the measuring frequency.

A current source with the proper impedance must be constructed because: 1) most regulated supplies that have current limiting have a large capacitor across the output terminals causing a low ac impedance, and 2) even the high-slewing-rate operational supplies usually have a network across the output terminals that reduces their impedance to a few thousand ohms at 1 kHz. To construct a high impedance supply use any common ungrounded voltage supply (Kepco ABC–series units) and feed the output through the circuit in Figure 3-3. Connect the output of this circuit to the unknown inductor (Figure 3-2e).

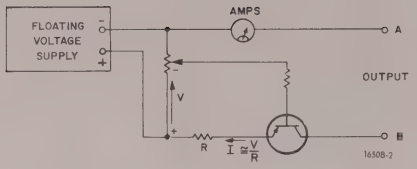

Figure 3-3. Dc-current supply for inductor measurements.

CAUTION

Short out the current source before disconnecting the inductor to prevent large transient voltages.

3.4 DC BIAS FOR AC RESISTANCE MEASUREMENTS.

A dc bias voltage and current may be applied to various types of nonlinear resistive elements such as diodes, varistors, and thermistors in order to measure small ac signal resistance. For voltage-sensitive devices, diodes, and varistors, the ac resistance is the slope of the dc voltage-current curve. For thermally sensitive devices, the ac resistance is equal to the dc resistance as long as the time constant is much longer than the period of the ac signal. Several methods of applying dc are shown in Figure 3-4.

Method 1. (Figure 3-4a.)

In this method all of the current supplied flows through the unknown. The current is limited to the amount given in Table 3-2. The dc source impedance should be low compared with that of the unknown, or the source should be shunted by a large capacitor as shown. If the dc supply is grounded, the bridge chassis will be off ground by a very low voltage.

Method 2. (Figure 3-4b.)

This method removes the dc supply from the bridge arm so that its impedance is not so important. The current in the unknown is equal to the current supplied multiplied by $R_B/(R_A + R_B)(R_B = 10\ k\Omega)$ and should be limited to that given in Table 3-2. The voltage applied should be limited to 71 V. If the dc supply is grounded, the bridge chassis may be at a potential of up to 37 V.

Method 3. (Figure 3-4c.)

This method permits grounding of both the bridge chassis and the dc supply. The current through the unknown is equal to the current supplied multiplied by $R_A + R_x$. The maximum current applied to the bridge is limited to 7 mA, and the voltage may be as high as 500 V if the current is limited to give a maximum power of 0.5 W.

Method 4. (Figure 3-4d.)

This method permits large currents through low resistors, since no current flows in the bridge. The resistor R_f should be large compared with the unknown, and the blocking capacitor, C_F, should be able to take the dc voltage $I_{dc}R_x$. The impedance of the blocking capacitor should be low compared with that of the unknown.

3.5 MEASUREMENTS WITH REACTANCE.

The ac resistance and conductance bridges of the 1656 are very useful for measurements on very low Q (high D) components and for making incremental measurements of nonlinear resistive components, like Thyrite varistors or diodes, and for measuring input and output impedances of field-effect transistors or transistor amplifiers, gyrators, impedance scalers, etc.

Table 3-2

MAXIMUM DC THROUGH INDUCTORS
OR RESISTORS
(METHODS 1 AND 2)

Range Multiplier		Maximum Current	R_A (Ratio Arm)
L	R		
100 μH	100 mΩ	100 mA	1 Ω
1 mH	1 Ω	100 mA	10 Ω
10 mH	10 Ω	71 mA	100 Ω
100 mH	100 Ω	22 mA	1 kΩ
1 H	1 kΩ	7.1 mA	10 kΩ
10 H	10 kΩ	2.2 mA	100 kΩ
100 H	100 kΩ	0.5 mA	1 MΩ

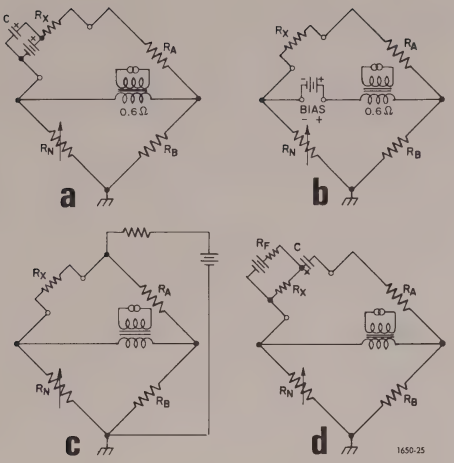

Figure 3-4. Methods of applying dc for ac resistance measurements.

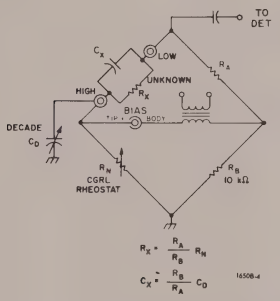

Figure 3-5. Circuit for measuring capacitive resistors.

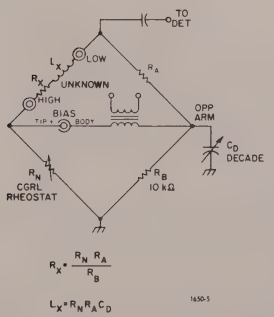

Figure 3-6. Circuit for measuring inductive resistors.

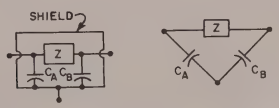

Figure 3-7. Shielded three-terminal impedance.

If the null is not sharp, i.e., sensitive to a small change in the CGRL dial position, the "resistance" is either capacitive or inductive. A capacitive resistance is measured by connecting an external capacitance decade box (C_D) from the HIGH UNKNOWN post on the bridge to the case (Figure 3-5). An inductive measurement is made by connecting an external capacitance decade box between the OPP ARM banana jack on the bridge and the case (Figure 3-6).

Measurements can be made in terms of conductance, also. The conductance bridge has R_N and R_B interchanged, causing the balance formulas to be as follows:

$$G_X = \frac{R_N}{R_A R_B}$$

$$C_X = \frac{R_N}{R_A} C_D$$

$$L_X = R_B R_A C_D$$

(Refer to para. 1.4 for term definitions.)

NOTE

A sliding null can occur if the unknown is inductive and of Q greater than 1 because R_A appears in the null equations of both R_N and L_X.

3.6 RESONANT FREQUENCY OF TUNED CIRCUITS.

The resonant frequency of a series or parallel tuned circuit may be found by means of an external variable-frequency oscillator and the ac resistance bridge. The external oscillator is connected as described in para. 2.4, and the tuned circuit is connected to the UNKNOWN terminal.

The frequency and the CGRL dial are then varied for the best null attainable. The bridge indicates, at balance, the effective series resistance of a series tuned circuit of the effective parallel resistance of a parallel tuned circuit, while the oscillator indicates the resonant frequency.

3.7 SHIELDED THREE-TERMINAL COMPONENTS.

When the unknown is shielded and the shield is not tied to either unknown terminal, a three-terminal component is formed (Figure 3-7). The impedance Z of the component itself is the direct impedance of the three-terminal system. To measure the direct capacitance of a three-terminal system, connect the third terminal to the panel of the instrument, using any grounded panel terminal or a ground lug with screw just below the UNKNOWN terminals. The capacitances to the shield have negligible effect as long as one of them is reasonably small (para. 4.6).

Often the shield of an inductor is not connected to either terminal. When the inductance and frequency are low so that stray capacitance across the inductor causes negligible error, the shield should be connected to the UNKNOWN terminal marked LOW. When the inductance

(or frequency) is high, the effective inductance is increased because of the shunting capacitance. The error is +100 $(\omega^2 L_x C_x)$% (para. 4.4). To avoid an inductance error, the shield may be tied to the panel of the bridge. The inductor terminal that has the larger capacitance to the shield should be tied to the LOW bridge terminal. A Q error results from the capacitance from the other UNKNOWN terminal to the shield but a better measurement of L_x is possible. (This connection does not affect the winding capacitance itself.)

3.8 REMOTE MEASUREMENTS.

Due to the small effect of stray capacitance to ground, particularly for capacitance measurements (para. 4.6), the unknown may be placed some distance away from the bridge. If at least one of the connecting leads is shielded, the capacitance between the leads is avoided. The shielded lead should be connected to the LOW UNKNOWN terminal and the bridge should be grounded. The other lead may also be shielded, at the cost of increased capacitance to ground. When low impedance measurements are made, the effect of the lead resistance and inductance should be considered (para. 4.9).

3.9 MEASUREMENT OF GROUNDED COMPONENTS.

If the component to be measured is connected directly to ground, the component may be measured with the case of the 1656 floating off ground.

Either unknown terminal of the unknown capacitor may be grounded. Grounding the low terminal tolerates large capacitance from the case to ground but increases sensitivity to hum. However, most of the hum can be removed by the internal 1-kHz filter in the amplifier. Grounding the other unknown terminal decreases sensitivity to hum, but a capacitance of 1000 pF from the case to ground causes a 1% capacitance error (para. 4.6).

If the unknown is an inductor, the LOW terminal should be grounded.

Even when the bridge is floating, the bridge panel can be used as a guard terminal for three-terminal or remote measurements.

3.10 USE OF THE TYPE 1650-P1 TEST JIG.

3.10.1 General.

The Type 1650-P1 Test Jig provides quick connections to the bridge with a pair of conveniently located clip terminals. When the 1656 is set up for limit measurements (para. 3.11), the combination facilitates the rapid sorting of electrical components.

The jig is also useful for measurements on small capacitors because of its small zero capacitance and because the unknown component is positioned and shielded to make repeatable measurements possible.

3.10.2 Installation.

The test jig is connected to the bridge UNKNOWN terminals by means of the shielded Type 274 Connector attached to the jig. A three-terminal connection is necessary. The third connection is made by means of the screw, located directly below the UNKNOWN terminals, and the lug on the shield of the connector. This screw makes the ground connection to the jig and also holds the connector in place.

The leads of the test jig may be brought around in back of and underneath the bridge so that the jig may be located directly in front of the bridge without interference from the leads.

3.10.3 Residual Impedances of the Test Jig.

The residual resistance of the leads is about 80 mΩ (total) and the inductance is about 2 μH. The zero capacitance, when the leads are connected to the bridge, is negligible (≈ 0.2 pF). The shielded leads cause a capacitance to ground of about 100 pF each. Corrections may be necessary for the residual resistance and inductance when measurements are made on low impedances (para. 4.9). The capacitance to ground causes a −0.1% error in capacitance measurements, and can cause a D (1/Q) error up to about 0.007 for inductance measurements (paragraph 4.6).

3.11 LIMIT TESTING.

The Type 1656 may be set up to provide a go-no-go indication useful for component testing. The panel meter is used as the indicator. The setup procedure is as follows:

a. Balance the bridge with one of the components to be measured (preferably one within tolerance).

b. Offset the CGRL decade by the desired tolerance, if the tolerance is symmetrical, or by one half of the total allowable spread if unsymmetrical.

c. Adjust the SENSITIVITY control for a five-division meter deflection.

d. Set the CGRL decade to the center value (the nominal value if the tolerance is symmetrical).

e. Connect each component to the bridge (or Type 1650-P1 Test Jig). If the meter deflection is less than five divisions, the component is within limits.

When the unknown has a tolerance greater than ±10%, the limits may be in error by more than 1% if the above method is used. A sure method is to set the CGRL decade so that unknown components at both limits give the same deflection.

3.12 PRECISION DIFFERENCE MEASUREMENTS.

Standards, and other components, of nearly equal value can be compared to each other to 0.01% accuracy, if they are measured near full scale on the CGRL decade, so that full resolution is used. However, to avoid bridge errors of more than 0.01%, both measurements should be made with the same settings of the first digit of the CGRL decade. It is good practice to use as many 9's as possible in the first digits, placing any X as far to the right as possible. In this manner, settings above or below 10.000 can be obtained with the first digits left unchanged. An accuracy of 0.01 is possible if the difference is less than 5%.

REACTANCE CHART

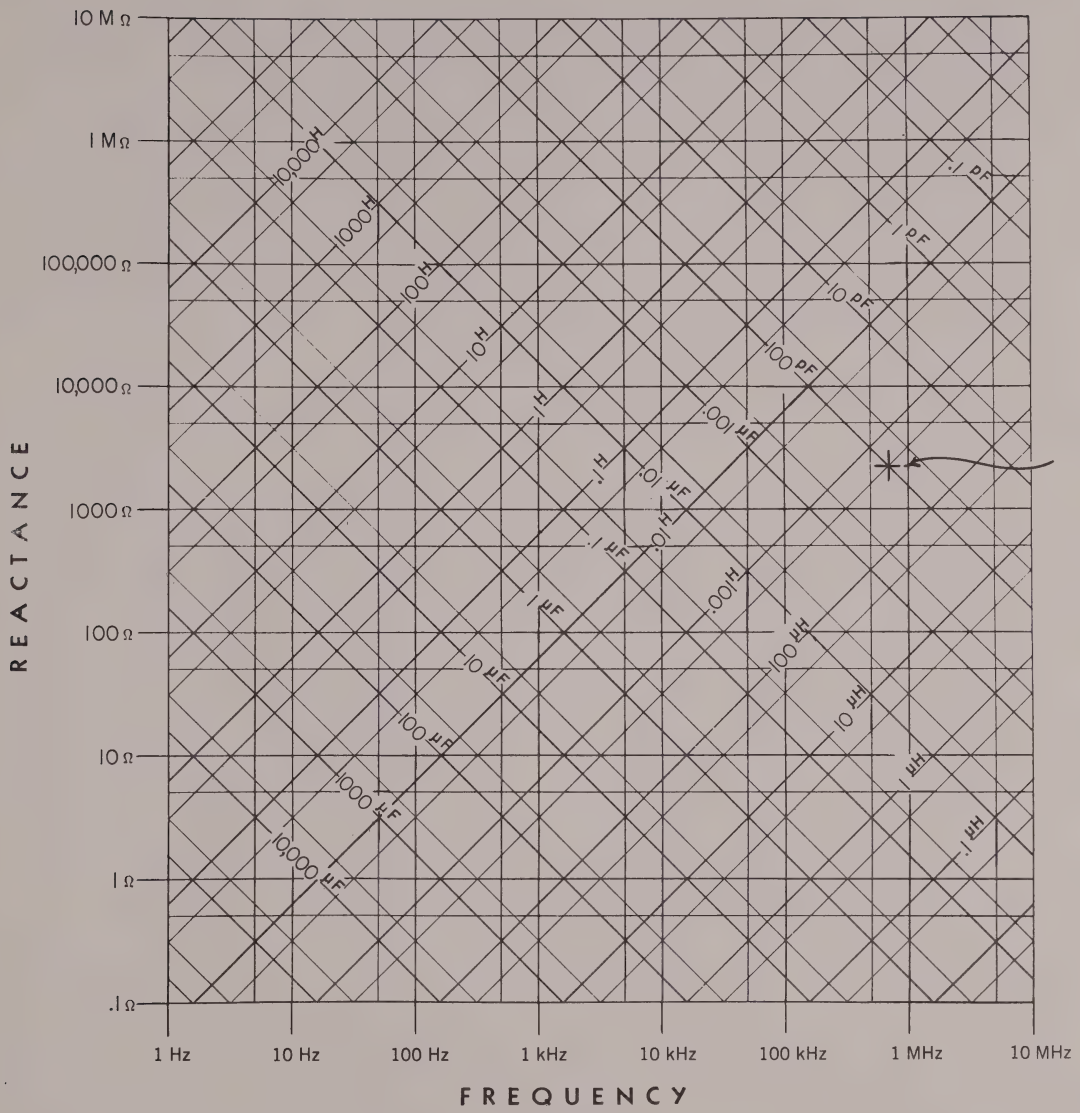

FIGURE 3-8

Figure 3-8 is the complete chart, used for rough calculations. Figure 3-9, which is a single decade of Figure 3-8 enlarged approximately 7 times, is used where two or three significant figures are to be determined.

TO FIND REACTANCE

Enter the charts vertically from the bottom (frequency) and along the lines slanting upward to the left (capacitance) or to the right (inductance). Project horizontally to the left from the intersection and read reactance.

TO FIND RESONANT FREQUENCY

Enter the slanting lines for the given inductance and capacitance. Project downward and read resonant frequency from the bottom scale.

REACTANCE CHART

Always obtain approximate value from Figure 3-8 before using Figure 3-9

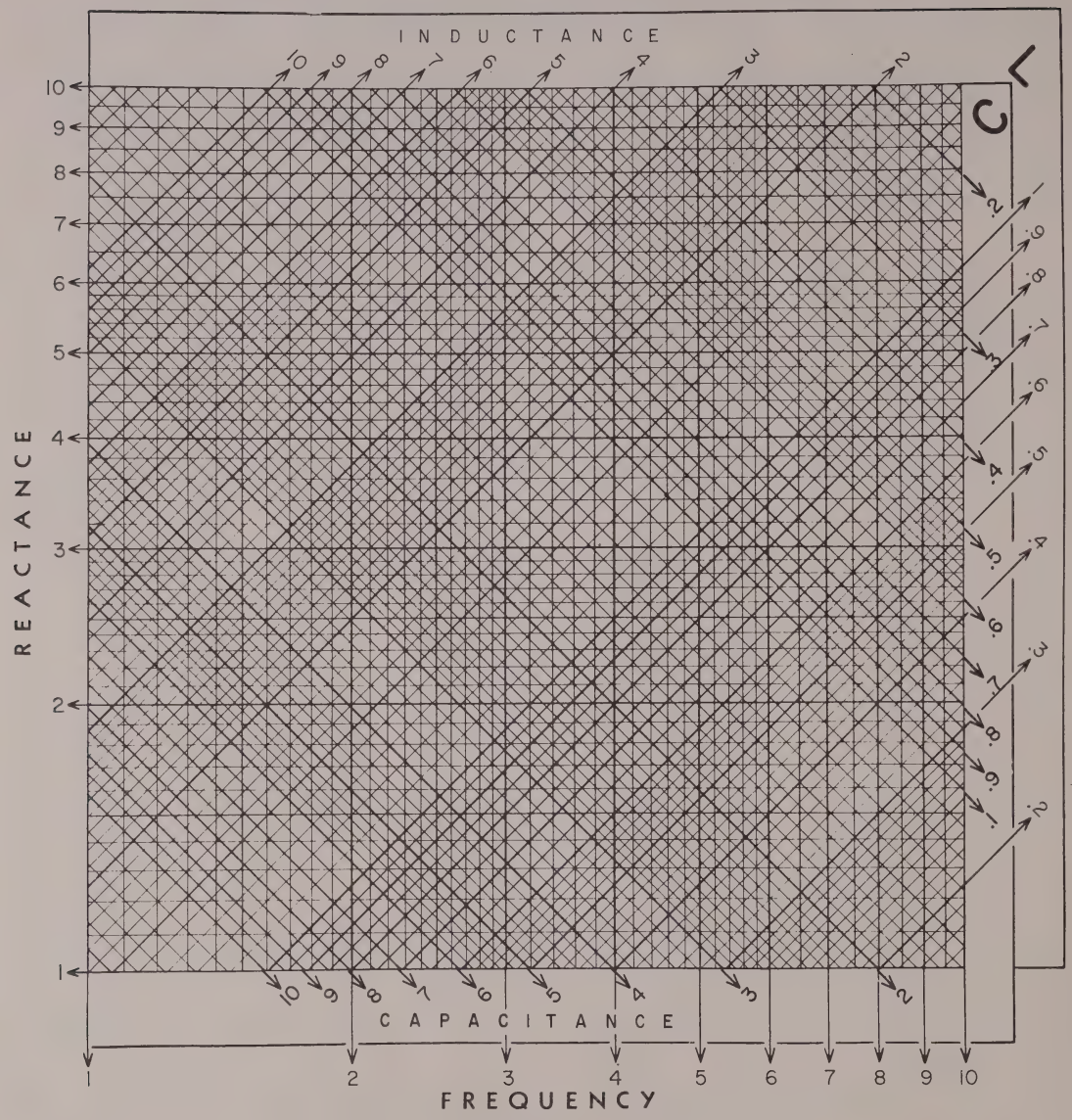

FIGURE 3-9

Example: The point indicated in Figure 3-8 corresponds to a frequency of about 700 kHz and an inductance of 500 μH, or a capacitance of 100 pF, giving in either case a reactance of about 2000 ohms. The resonant frequency of a circuit containing these values of inductance and capacitance is, of course, 700 kHz, approximately.

USE OF FIGURE 3-9

Figure 3-9 gives additional precision but does not place the decimal point, which must be located from a preliminary entry on Figure 3-8. Since the chart necessarily requires two logarithmic decades for inductance and capacitance for every single decade of frequency and reactance, unless the correct decade for L and C is chosen, the calculated values of reactance and frequency will be in error by a factor of 3.16.

Example: (Continued) The reactance corresponding to 500 μH or 100 pF is 2230 ohms at 712 kHz, their resonant frequency.

Accuracy—Section 4

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4.3 AC RESISTANCE AND CONDUCTANCE 4-1
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4.6 EFFECTS OF CAPACITANCE TO GROUND 4-3
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4.1 GENERAL.

The basic accuracy of the 1656 at 1 kHz for C, G, R, and L measurements is 0.1% plus one digit (0.1% of full scale). An extra 0.2% is added on the lowest R and L ranges and highest C and G ranges (to account for switch resistance variations in the 1-Ω ratio arm). Therefore, if there is a choice of ranges (such as when measuring even decade values) best accuracy is attained when using the lower possible multiplier, except in the cases when this is the lowest R or L range.

The basic D-Q accuracy at 1 kHz is ±5% ±.001 in D or Q. This last term is the phase angle accuracy of the bridge, 0.001 radians. For components with D values of less than 0.02 (or Q values more than 50), this is the more important tolerance term. It is a little difficult to convert this to a Q accuracy. One way is to convert the Q readings to D values (D = 1/Q) and then add and subtract the tolerance and reconvert these limits.

Another way is to use the reciprocal relationship between the two outer scales. The range of Q covered by the 0.001 D accuracy term can be quickly obtained by moving the DQ dial + and −0.001 on the outer scale and noting the readings on the second scale. For example, this would indicate quickly that a measured Q of 1000 could be between 500 and ∞.

Measurements on very low values of R, C or L must be connected to account for the residual impedances of the bridge terminals and any connecting wires to get full accuracy (see para. 4.9). These connections are important for measurements on very low or very high impedances. A change in measurement frequency can reduce the errors in many cases. Accuracy of measurements at frequencies other than 1 kHz, at high D (low Q) and with shunt loading to ground, are discussed in the following paragraphs.

4.2 DC RESISTANCE AND CONDUCTANCE.

The accuracy of dc resistance or conductance measurements is 0.1% plus 0.01% of full scale on all but the lowest resistance and highest conductance ranges, where an extra 0.2% error term is added. There is sufficient sensitivity to obtain this accuracy.

The detector dc offset voltage depends somewhat on the impedance of the bridge. Therefore, for best accuracy, the dc zero should be checked after a null has been obtained, and if it is appreciably off, it should be readjusted and a second balance made.

For low-resistance measurements, short, heavy leads should be used as connections to the unknown. The zero resistance of the leads should be measured with the free ends connected together and subtracted from the bridge reading with the unknown in place. The user should be particularly careful when using banana-pin connections. For best connection to the bridge, tighten the binding post hard enough to notch the wire inserted in the hole.

4.3 AC RESISTANCE AND CONDUCTANCE.

Full bridge accuracy is not obtained for ac resistance measurements unless an external phase-balancing capacitor is used (see para. 3.5), because a phase unbalance will prevent a good null condition, even when the unknown resistor has negligible reactance. Accuracy substantially better than ±0.5%, given in the specifications, is possible when measuring "pure" resistors, except when the residual bridge inductance or capacitance combines with this pure resistance to give the combination an appreciable phase

angle. These residuals affect very low and very high resistance values, respectively.

The phase-angle limitation is proportional to frequency, so that if the bridge is not balanced by external capacitance (see 3.5), the accuracy is 0.5% f/1 kHz, plus the additional high frequency and high Q errors given in the specifications.

As with dc resistance, very short heavy leads should be used for low-resistance measurements and the resistance of these leads measured and subtracted from the final measurement (see para. 4.2). For ac measurements, the lead series inductance and shunt capacitance should also be considered. For very low resistance measurements, inductance should be reduced by using as short leads as possible and by twisting them together. The resulting increased capacitance will not be a problem. Conversely, for high-resistance measurements the leads should still be short, but should be spread as far apart as possible to reduce shunt capacitance.

4.4 INDUCTANCE AND Q.

The 1-kHz accuracy of unusually high-Q inductance measurements is ±0.1% +0.01% of full scale, on all but the lowest inductance range, where there is an additional ±0.2%. The user has the choice of measuring series or parallel inductance over the Q range from 1 to 10. In most cases L_s is used for specifying components, and this bridge has a Q range of 0.02 to 10. Above Q's of 10, the L_p bridge must be used, but the difference between L_s and L_p is only 1% at a Q of 10 and becomes quickly negligible for high Q values. For Q values above 10, the quickest way to convert to L_p is to use the equation $L_s = L_p\ (1\text{-}D^2)$ (which has an error of less than 0.01% at Q = 10 or D = 0.1); note that the D value for the L_p bridge can be read on the first (low D) scale of the dial, because these two scales use reciprocals. (See para. 1.5 for general conversion formulas.)

The Q accuracy is given as two terms ±5% ±0.001 in 1/Q. The second term is negligible for measurements on the L_s bridge (Q less than 10), but the second term becomes dominant for Q values above 20 on the L_p bridge (see para. 4.1). This Q accuracy holds for C readings down to 1/20th full scale.

The residual (zero) inductance of the bridge terminals is approximately 0.15 μH and should be subtracted from the measured value of very low inductances, as should the inductance of any connecting leads.

The residual resistance of the bridge is 1 milliohm, which causes a small D (1/Q) error. This error is less than 0.001 if L_x is more than 160 μH. If long leads are used to connect to the unknown, this error can become appreciably greater and require a correction. The D error is

$$+\frac{R_o}{\omega L_x} \qquad \left(\text{the Q error is} -Q^2\frac{R_o}{\omega L_x}\right)$$

where R_o is the total lead resistance.

The residual zero capacitance of 0.3 pF theoretically causes a 0.1% error, even for inductors over 80 H. However, this small capacitance is almost always negligible compared with the capacitance of the winding of such a large inductor. If the inductor is shielded, a three-terminal measurement will reduce the effect of stray capacitance to the shield (para. 3.8). In order to reduce the effect of the winding capacitance it is necessary to reduce the measurement frequency. The inductance error due to a shunt capacitance C_o is $\omega^2 C_o L_x^2$, and this amount should be subtracted from the bridge reading (para. 4.8)

The inductance accuracy is reduced if Q is small by the typical additional error terms of ±(0.2/Q)% and ±(0.5/Q^2)% at 1 kHz. The first term is inherent in the bridge but the second is primarily to allow for the difficulty in balancing low-Q inductors, because of interaction of the two adjustments ("sliding null")*. With patience and technique much better accuracy is possible (see para. 2.5).

Accuracy and Q range for frequencies other than 1 kHz are discussed in para. 4.7, 4.8, 4.10 and 4.11.

Differences between inductance measurements on different instruments is not uncommon (even though both instruments may be within their specifications) for a number of reasons.

a. Many inductors have relatively low Q values so that L_s-L_p differences are important and one must know which is specified (usually L_s).

b. Most bridges have additional errors at low Q (see above).

c. The inductance of an inductor is quite frequency dependent unless the measurements are made well below their resonant frequency. Either the frequency of measurement or the "low-frequency value" should be specified. The low-frequency value is simply the value at a frequency low enough so that a change in frequency has no effect on inductance. Note that some power transformers and chokes are actually capacitive at 1 kHz and should be measured at a lower frequency.

d. Iron-cored inductors are level dependent and must be measured at a specified level to get measurement agreement unless the "low-level" value is specific. The low-level value is the inductance at a voltage level that is low enough so that further reduction in level causes no appreciable change in inductance.

4.5 CAPACITANCE AND D.

The 1-kHz accuracy of reasonably low-D capacitance measurements is ±0.1% ±0.01% of full scale or all but the highest capacitance range when there is an additional ±0.2%. The user has a choice of measuring series or parallel capacitance, over the D range of 0.1 to 10. In most cases C_s is used for specifying components and few capacitors have D values greater than unity so that the C_s bridge can usually

*Hall, H.P., Op. Cit.

be used. Conversion formulas from C_p to C_s and, vice versa, are given in para. 1.5.

The D accuracy is given with the terms ±5% ±0.001. When D is less than 0.02, the second term becomes dominant. D accuracy of ±0.001 is consistent with a 0.1% C accuracy, since they represent quadrature deviations of similar size, i.e., $Y = j\omega C[(1 - jD) \pm \frac{\Delta C}{C} \mp j\Delta D]$. In many circuits, a D change is just as important as a comparative change in capacitance value. This D accuracy holds for C readings down to 1/20th full scale, below which there is adequate C resolution for a 0.001 D adjustment.

The residual ("zero") capacitance of the bridge is approximately 0.3 pF. This value should be subtracted from the measured value of small capacitors. Likewise, the capacitance of any connecting leads should be measured and subtracted. It should be noted that two-terminal measurements of very small capacitors will depend on the geometry of the connection, and an easily repeatable configuration must be used to obtain good comparisons between measurements. The use of the 1650-P1 Test Jig reduces this variation (see para. 3.11).

The residual resistance of the bridge is 1 mΩ, which theoretically causes a D error of 0.006 when C_x = 1000 μF. In practice, capacitors of this size have such large D values that such an error is negligible. However, if leads are used to connect large capacitors, this D error can become important and a correction should be made. The D error is $+\omega R_o C_x$ (where R_o is the lead resistance), and this amount should be subtracted from the D reading.

The residual bridge inductance causes a 0.1% capacitance error at a value of approximately 160 μF and a 0.6% error at 1000 μF at 1 kHz. The errors are usually negligible compared to the usual tolerances of capacitors this large. The added inductance of connecting leads could make substantially larger error (see para. 4.9). However, generally these large capacitors should be measured at 120 Hz where this error is greatly reduced.

The capacitance accuracy is reduced at 1 kHz, if D is larger by the additional terms of 0.2% D and 0.5% D^2. The first term is inherent in the bridge, but the second is primarily to allow for the difficulty in balancing high-D capacitors because of the interaction between the two adjustments (sliding null). With patience, much better accuracy is possible (see para. 2.5).

Capacitance measurements at other frequencies are discussed in para. 4.10 and 4.11.

4.6 EFFECTS OF CAPACITANCE TO GROUND.

The Type 1656 Bridge generally measures "ungrounded" components, since neither UNKNOWN terminal is connected directly to the panel. The panel should be connected to a good ground, especially if high-impedance components are to be measured. If the panel is not grounded, stray capacitances from the UNKNOWN terminals and panel to ground can produce an effective capacitance across the UNKNOWN terminals. With the panel grounded, capacitances from the UNKNOWN terminals to ground have a much less serious effect. (For measurements of grounded components refer to para. 3.9).

The effects of stray capacitances to the panel (ground) are usually negligible in the capacitance bridges (Figure 4-1). Capacitance from the LOW terminal to ground (C_A) shunts the detector and causes no error. Capacitance from the other terminal to ground (C_B) shunts the standard capacitor (C_T) and produces an error of

$$-\frac{C_B}{C_T} \times 100\% = \frac{C_B}{0.1\,\mu F} \times 100\%$$

Since C_T is large, it takes 1000 pF to produce a 1% error (when D is small).

In the inductance bridge (Figure 4-2) C_A is across the detector and has no effect, but C_B shunts the CGRL rheostat. Capacitance across this rheostat causes a D (1/Q) error of $-\omega R_N C_B$. The L error is usually negligible except when Q_x is very low.

$$L\ meas = L_x\ (1 + \frac{\omega R_N C_B}{Q_x})$$

Thus, for inductance measurements, it is desirable to connect the terminal with the most capacitance to ground to the UNKNOWN terminal marked LOW.

4.7 D AND Q ACCURACY.

D (or 1/Q) accuracy is dependent upon frequency and the CGRL dial setting.

CGRL dial setting of 1 or above:

1 kHz or lower: ±0.001 ± 5%

Above 1 kHz: ±0.001 (f/1 kHz) ±5%

CGRL dial setting below 1:

1 kHz or lower: ±(0.001)(1/CGRL dial setting) ±5%

Above 1 kHz: ±(0.001)(1/CGRL dial setting) (f/1 kHz) ±5%

NOTE

The percentage accuracy, 5%, applies directly to Q, but the fixed-accuracy term, ±0.001, does not apply directly because Q = 1/D = 1/±0.001 = ±1000, which is not true. Also, the corrections for residual and lead impedances must be taken into account (para. 4.9).

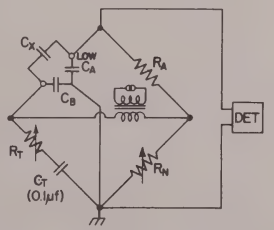


Figure 4-1. Capacitance to ground for capacitance measurement.

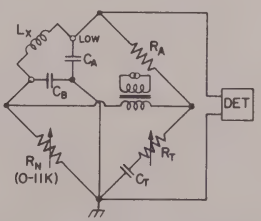


Figure 4-2. Capacitance to ground for inductance measurement.

This DQ accuracy holds for high-D and low-Q values as long as a good null is obtained. A D or Q error equal to the C or L error results if a good null is not obtained for very lossy components because of a sliding null (see para. 2.5, 4.4 and 4.5).

4.8 D AND Q RANGES VS FREQUENCY.

The D and Q readings and ranges are functions of frequency. Also, in order to avoid errors in the C and L readings, the D or Q of the unknown is further limited. The resulting allowable D and Q ranges are given in terms of frequency and D or Q of the unknown at the measurement frequency in Figure 4.3.

The numbers on the various limits refer to the explanations below:

1. End of DQ rheostat range.
2. First division on Low D (0.001) and High Q (1000) scales (no C or L error).
3. Limited by D of standard capacitor (no C or L error).
4. 20-Hz nominal limit because of meter response (see para. 4.10)
5. 20 kHz, a nominal limit (range narrow above 20 kHz).
6. C or L error of .25% due to capacitance across C_T arm in C_s bridge (much less than 0.5% D^2 specification).
7. C or L error of 1% due to inductance in DQ rheostat in C_s bridge (specification 0.2% D_f kHz).
8. End of the low D and high Q scales. Use the low Q scale to extend the low D range, and the high D scale to extend the high Q range.
9. C and L error of 1% even if good null is reached in spite of sliding null (see para. 2.5).
10. C and L error may be 2% above this line owing to inductance in the DQ potentiometer.

Note that in the overlap area either the C_s or the C_p bridge may be used. Below 100 Hz is an area not covered by either bridge, requiring an external adjustment (refer to paragraph 4.10).

4.9 CORRECTIONS FOR RESIDUALS.

At high frequencies, the errors resulting from the residual bridge impedances and from the connecting lead impedances become more important, often requiring corrections. The formulas for the correction terms are given in Table 4-1. These correction terms are first-order terms only.

4.10 OPERATION BELOW 1 kHz.

The wide overlap of ranges (Figure 4-3) permits D and Q coverage down to 100 Hz without external adjustment. Below 1 kHz, more of the low D and high Q range can be used than is calibrated. In this region the low Q scale can be used to indicate D directly and the high D scale used to indicate Q directly with a maximum additional error of 2%.

Below 100 Hz there is a D and Q range not covered by the internal DQ adjustment. An external rheostat or decade box may be used to extend the range of any of the D or Q scales. However, to avoid error, the low D and high Q ranges should not be extended beyond a value of 1 at frequency of measurement (Figure 4-3).

Table 4-1

CORRECTION TERMS FOR ERRORS DUE TO RESIDUAL AND LEAD IMPEDANCES*

Measured Quantity	Series Resistance R_o (1 mΩ + leads)	Series Inductance L_o (0.2 μH + leads)	Parallel Capacitance C_o (0.5 pF + leads)
C_s	No Error	$-\omega^2 L_o C_x^2$	$-C_o (1 - D_x^2)$
D	$-\omega C_x R_o$	$-\omega^2 L_o C_x D_x$	$+D_x \frac{C_o}{C_x} (1 + D_x^2)$
C_p	$+2 R_o \omega D_x C_x^2$	$-\omega^2 L_o C_x^2 (1 - D_x^2)$	$-C_o$
D	$-\omega C_x R_o (1 + D_x^2)$	$-\omega^2 L_o C_x D_x (1 + D_x^2)$	$+\frac{C_o}{C_x} D_x$
R	$-R_o$		
L_s	No Error	$-L_o$	$-\omega^2 C_o L_x (1 - \frac{1}{Q_x^2})$
Q	$+Q_x^2 \frac{R_o}{\omega L_x}$	$-\frac{L_o}{L_x} Q_x$	$+\omega^2 C_o L_x (Q_x + \frac{1}{Q_x})$
L_p	$+\frac{2R_o}{Q\omega}$	$-L_o (1 - \frac{1}{Q^2})$	$-\omega^2 C_o L_x^2$
Q	$+\frac{R_o}{\omega L_x} (1 + Q^2)$	$-\frac{L_o}{L_x} (Q + \frac{1}{Q})$	$+\omega^2 C_o L_x Q$

*Add or subtract from measured value as indicated.

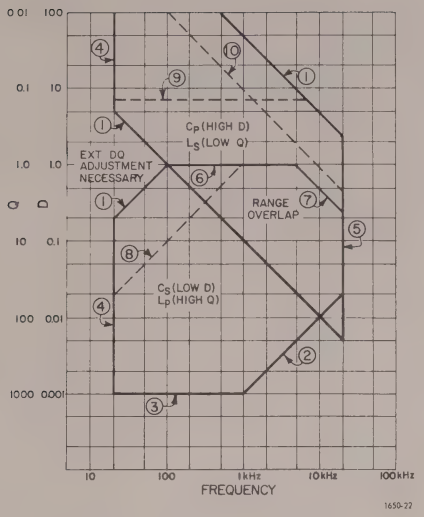


Figure 4-3. DQ ranges vs frequency.

The low D and low Q scales are directly proportional to frequency. Therefore, the total D or Q value is the sum of the dial reading plus the ωRC product due to the external resistor. That is:

low D = (low D dial reading + 0.628R x f (kΩ, kHz)

low Q = (low Q dial reading + 0.628R x f (kΩ, kHz)

The low Q circuit has a fixed 32-ohm resistor in series with the potentiometer, but that is included in the dial calibration.

The high D and high Q scales are inversely proportional to frequency, and the effects of the internal and external resistors are therefore not additive. The DQ rheostat should be set to a minimum (high Q = ∞ or high D = 50), and the whole adjustment will be on the external resistance and will be:

$$\text{high Q} = \frac{1.592}{fR}$$

$$\text{high D} = \frac{1.592}{f(R + 0.032)}$$

where f is in kHz and R is in kΩ.

It is difficult to state the minimum usable test frequency limit sensitivity. Below 20 Hz the detector pulsates considerably, but measurements are still possible. The detector gain falls off below 5 Hz, but some measurements are possible down to 2 Hz. Note that the external signal should be applied at the BIAS jack at these low frequencies (see para. 2.4).

4.11 OPERATION ABOVE 1 kHz.

The specifications include typical accuracy terms for measurements at higher frequencies. These apply to all measurements up to 50 kHz, but above this value they become so large as to be useless (20% for L and C, and 30% for R at 100 kHz).

Substantially better accuracy is usually obtainable if a few restrictions are used above 20 kHz.

1. Use the C_p and L_s bridges. These have better DQ coverage and fewer sources of error (see Figure 4.3).

2. CGRL settings are limited to settings up to 4,000 to keep the impedance of this arm low.

When these restriction are observed, the typical accuracy is that of Table 4-2. The bridge sensitivity falls off substantially at these frequencies and an external detector may be necessary to get the accuracy at impedance extremes. Note also that the residual connections become large (see paragraph 4.9).

Note that each instrument is not tested at high frequencies, so that the high frequency accuracy may vary. This is why this data is not an actual specification, but is referred to as typical behavior.

Table 4-2

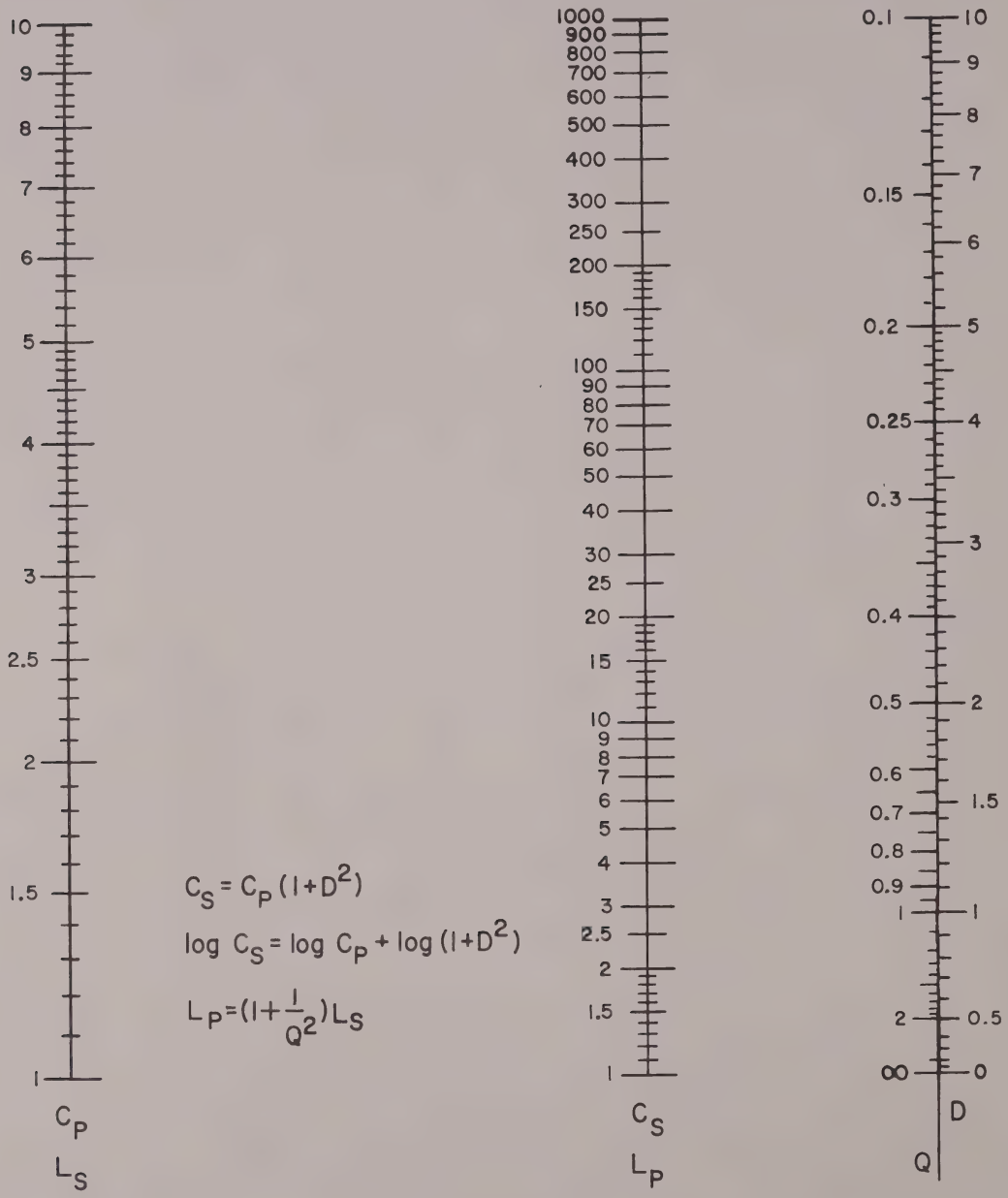
C_p-L_s ACCURACY BETWEEN 0.4 AND 4 ON THE CGRL DECADE

Frequency	Basic Bridge Accuracy	Limits of Error Added Above 20 kHz	Net Accuracy Limits*
50 kHz	±1%	+0, -1%	+1%, -2%
100 kHz	±1%	+0, -2.5%	+1%, -3.5%

*Below line 10 (extended) in Figure 4-3.

NOMOGRAPH FOR CONVERSION OF C, L, D AND Q AT 1 kHz

The nomograph below greatly simplifies the process of converting from series to parallel value (or vice versa) of inductance and capacitance, for values of dissipation factor up to 10 (Q down to 0.1). To illustrate use of the nomograph, assume a parallel capacitance of 2 μF, and a D of 7. A straight line connecting these two points is seen to cross the center (C_S) bar at 100. Therefore, the equivalent series capacitance is 100 μF.



$$C_S = C_P(1+D^2)$$

$$\log C_S = \log C_P + \log(1+D^2)$$

$$L_P = \left(1+\frac{1}{Q^2}\right)L_S$$

Theory—Section 5

5.1 GENERAL 5-1
5.2 D AND Q 5-1
5.3 THE 1656 BRIDGE CIRCUITS 5-2

5.1 GENERAL.

A bridge is a circuit that measures an unknown impedance in terms of other known impedances by means of a known relationship between these components when a balance is made. If a voltage is applied to the basic bridge circuit of Figure 5-1 and one or more impedance values are adjusted to give zero voltage on the detector, the impedance values are related by the expression:

$$Z_x = \frac{Z_1 Z_2}{Z_3} \quad \text{or} \quad Z_x = Z_1 Z_2 Y_3$$

In the dc Wheatstone bridge all the impedances are resistance, and only one must be adjusted for a balance or null on the detector (usually a second resistance is adjustable in fixed steps to select range). Ac impedances are complex, having both real and imaginary parts, which can also be expressed as magnitude and phase angle. Therefore, two adjustments must be made to balance both the real and imaginary parts of the unknown impedance. The above equations become

$$R_x + jX_x = (R_1 + jX_1)\frac{Z_2}{Z_3}; \text{ or } R_x + jX_x = Z_1 Z_2 (G_3 + jB_3)$$

$$G_x + jB_x = (G_1 + jB_1)\frac{Y_2}{Y_3}; \text{ or } G_x + jB_x = Y_1 Y_2 (R_3 + jX_3)$$

The GR 1656 Impedance Bridge contains six bridge circuits to measure resistance, conductance and series and parallel capacitance and inductance (see para. 1.5). These circuits and their balance equations are given in para. 2.1.

The resistance and conductance bridges may be used for ac or dc, but for ac have no internal phase or imaginary balance. If the phase angle of the unknown is large, an external adjustable component may be used (see para. 3.5). The C and L bridges have phase angle balances, the phase being expressed as D or Q (see para. 5.2).

Bridges have several advantages over other impedance-measurement circuits. Besides measuring the unknown in terms of known impedances (rather than as a relationship between voltages and currents), if all components are linear, the balance condition is independent of the signal level applied, nor does the balance condition change if the oscillator and detector are interchanged. In the 1656, the ac level is adjustable to allow detection of nonlinearities in the unknown, and the fixed dc level is low to avoid excessive power dissipation (see para. 3.4).

5.2 D AND Q.

An important characteristic of an inductor or a capacitor, and often of a resistor, is the ratio of resistance to reactance or of conductance to susceptance. The ratio is called dissipation factor, D, and its reciprocal is storage factor, Q. These terms are defined in Figure 5-2 in terms of phase angle θ and loss angle δ. Dissipation factor is directly proportional to energy dissipated, and storage factor to energy stored, per cycle. Power factor ($\cos\theta$ or $\sin\delta$) differs from dissipation factor by less than 1% when their magnitudes are less than 0.1.

In Figure 5-2, R and X are series resistance and reactance, and G and B are parallel conductance and susceptance, of the impedance or admittance involved.

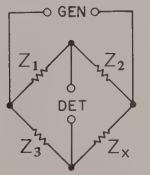


Figure 5-1. The general Wheatstone bridge circuit.

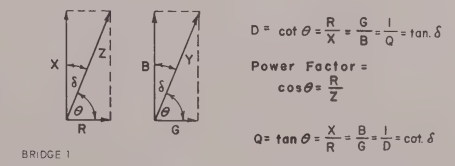


Figure 5-2. Vector diagram showing the relations between factors D and Q, and angles θ and δ.

Dissipation factor, D, which varies directly with power loss, is commonly used for capacitors. Storage factor, Q, is more often used for inductors because it is a measure of the voltage step-up in a tuned circuit. Q is also used for resistors, in which case it is usually very small.

5.3 THE 1656 BRIDGE CIRCUITS.

5.3.1 General.

The basic bridge circuits used are shown in para. 2.1 and the full circuit in Figure 7-9. The instrument uses the same bridge components in the various bridge circuits. The main adjustment is a lever-switch decade resistor with precision wire-wound resistors in the first decade and metal-film resistors of suitable precision in the succeeding decades. The ratio arm resistors are all GR wire-wound types, and the DQ rheostat is also wire-wound with a 54-dB logarithmic range. The standard capacitor is a GR precision mica unit externally padded to tight tolerance.

5.3.2 Bridge Switching.

The CGRL MULTIPLIER switch (S101) selects the bridge range by switching in various ratio-arm resistors. Clockwise rotation of this two-rotor switch increases the multiplier value for the G, R, L, and C bridges. Both ends of the range resistor are switched out so that the unused resistors can be grounded to reduce capacitance across this arm. Double, solid-silver contacts ensure low switch resistance and long switch life.

The CGRL PARAMETER switch (S102) selects the bridge circuits. The actions of this switch are such that it (1) selects the correct rotors of S101 and grounds one of the unused rotors, (2) selects the correct standard arm, and (3) reverses the bottom two arms of the bridge to form the L and R or C and G bridges.

The function switch sets up the correct internal source and detector circuits for the desired operation. When this switch is in either of the AC EXTERNAL positions, the EXT GEN terminals are connected to the bridge circuit through a bridge transformer.

5.3.3 Compensation Techniques.

The design of a bridge requires many sublities to insure high accuracy over a wide range of impedance and frequency. These include the addition of several components which don't appear directly in the balance equations, but are required to compensate for undesired inductance and capacitance in the bridge circuit. These are listed below (for component descriptions refer to the full circuit diagram, Figure 7-9).

Capacitors on the main decade: Two of these capacitors transform the main decade into a three-terminal network to provide effective inductance to balance out stray capacitance shunting the decade. The remaining capacitors compensate for the resulting small error in the value of the standard capacitor bridge arm.

C3: This capacitor compensates for the inductance of the 1-Ω ratio arm (R5).

C4: This capacitor compensates for the inductance of the 10-Ω ratio arm (R6).

C7 and C8: These capacitors correct the phase angle of the DQ potentiometer (R^2) to compensate for the inductance of the winding. Without compensation, this inductance would cause an error in C_s and L_p at high frequencies, and in C_p and L_s when the unknown has a very low Q or high D.

5.3.4 Bridge Sources and Detectors

The dc bridge is supplied by one 1 1/2-V D cell which is current limited by a series 15-Ω resistor to limit its maximum current to 100 mA. The voltage of this cell is checked, under load, in the BAT CHECK 2 position of the function switch. If this cell has low voltage it may still be used, but the sensitivity will be reduced. (It is not used for ac measurements).

The dc detector is an FET chopper dc amplifier. It consists of an input, low-pass filter to reject hum and other noise, a shunt FET chopper, a sensitivity control, tuned ac amplifier, demodulator and meter circuit. Its sensitivity is 10 μV/mm and input impedance is approximately 100 kΩ. It has a panel ZERO adjustment and internal adjustments for FET bias and capacitance compensation. (See paragraph 6.3.3 for information on making these adjustments.)

The ac source is a 1-kHz transistor RC Wien-bridge oscillator. The output voltage is about 0.3 V at the secondary of the 10-to-1 step-down transformer. The OSC LEVEL control adjusts output voltage by adjusting the voltage across the transformer primary.

The ac detector is a five transistor, variable-gain amplifier, which uses a twin-T RC filter to obtain selectivity when on the AC INTERNAL 1 kHz position. This amplifier drives the panel meter to provide a visual ac null indication, and the output from the amplifier is supplied to the side panel DET phone jack.

The ac oscillator and detector combined draw approximately 10 mA from the internal 6-V battery.

Service and Maintenance—Section 6

6.1 GR FIELD SERVICE 6-1
6.2 MINIMUM PERFORMANCE STANDARDS 6-1
6.3 CALIBRATION CHECKS 6-1
6.4 TROUBLE ANALYSIS 6-2
6.5 REPAIR NOTES 6-4
6.6 CALIBRATION PROCEDURE 6-5
6.7 KNOB REMOVAL . . . . . .
6.8 KNOB INSTALLATION . . . . . .

6.1 GR FIELD SERVICE.

The two-year warranty attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see last page of manual), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial, ID, and type numbers of the instrument.

6.2 MINIMUM PERFORMANCE STANDARDS.

The fifteen checks listed in Table 6-1 are given so that it can be determined that the instrument is in proper working condition (1) on receipt of a new bridge, (2) after a period of non-use, or (3) after repairs have been made to the bridge. If any specifications (READ column) are not met, the right-hand columns of Table 6-1 should identify the faulty component. Measurements should be made between 15°C and 35°C at less than 85% RH (see specifications). Table 6-2 lists the recommended test equipment for these checks plus the equipment needed for the calibration procedures given later. Figure 6-1 shows the equipment connected in a block diagram form.

6.3 CALIBRATION CHECKS.

6.3.1 CGRL Decade.

Set the PARAMETER switch of the 1656 to R, the function switch to DC INTERNAL 1 1/2 V and the MULTIPLIER switch 1 kΩ. Connect a GR type 1433-F, G, -N, -W, or -X Decade Resistor to the UNKNOWN.

Set the left most CGRL decade lever switch to 1 and all other lever switches to 0. Adjust the 1433 for a balance as indicated by the 1656 front-panel meter. Repeat this procedure for all the remaining CGRL decade settings. The 1433 should be set to within ±0.1% ±1 Ω of the CGRL decade setting. Any readings out of tolerance will indicate a defective resistor in the CGRL decade.

6.3.2 DQ Dial.

Connect to the UNKNOWN terminals a 1.0 μf standard capacitor (GR type 1409-Y) in parallel with a decade resistor with an upper limit of at least 10.0 kΩ and a lower

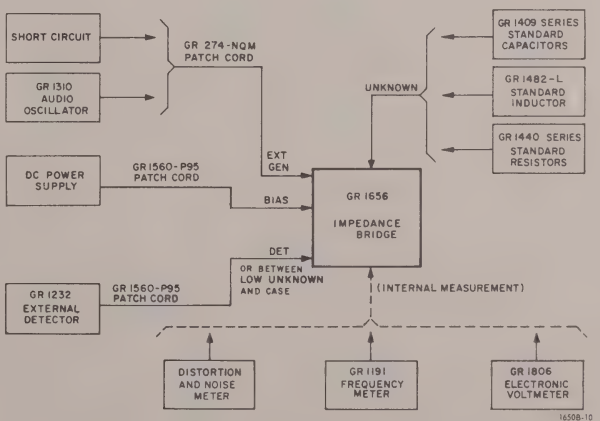


Figure 6-1. Test setup for service and maintenance of 1656.

Table 6-1

ACCURACY AND OPERATIONAL CHECKS

EXTERNAL STANDARD		PARA. Switch	Function Switch	CGRL MULT	Read*	Bridge Components in Circuit		
GR Cat. No.	Value					R_A	Standard arm	R_N
1440-9601	1 Ω	R	INT 1½ V	100 mΩ	R = 10.000 ± 0.31%	R5	R4	CGRL
1440-9111	10 Ω	R	INT 1½ V	1 Ω	R = 10.000 ± 0.11%	R6	R4	CGRL
1440-9621	100 Ω	R	INT 1½ V	10 Ω	R = 10.000 ± 0.11%	R7	R4	CGRL
1440-9631	1 kΩ	R	INT 1½ V	100 Ω	R = 10.000 ± 0.11%	R8	R4	CGRL
1440-9631	1 kΩ	R	INT 1 kHz	100 Ω	R = 10.000 ± 0.5%**	R8	R4	CGRL
1440-9631	1 kΩ	G	INT 1½ V	100 μ℧	G = 10.000 ± 0.11%	R9	R4	CGRL
1440-9631	1 kΩ	G	INT 1 kHz	100 μ℧	G = 10.000 ± 0.11%	R9	R4	CGRL
1440-9641	10 kΩ	R	INT 1½ V	1 kΩ	R = 10.000 ± 0.11%	R10	R4	CGRL
1440-9651	100 kΩ	R	INT 1½ V	10 kΩ	R = 10.000 ± 0.11%	R11	R4	CGRL
1440-9661	1 MΩ	R	INT 1½ V	100 kΩ	R = 10.000 ± 0.11%	R13	R4	CGRL
1409-9725	1 μF	C_S	INT 1 kHz	100 nF	C = 10.000 ± 0.11%	R9	DQ, C1	CGRL
1409-9725	1 μF	C_S	EXT 400 Hz†	100 nF	C = 10.000 ± 0.11%	R9	DQ, C1	CGRL
1409-9725	1 μF†	C_P	INT 1 kHz	100 nF	C = 10.000 ± 0.11%	R9	R3, DQ, C1	CGRL
1440-9631	1 kΩ‡				D = 0.16 ± 5%			CGRL
1482-9712	100 mH	L_S	INT 1 kHz	10 mF	L = 10.000 ± 0.11%	R8	R3, DQ, C1	CGRL
1482-9712	100 mH	L_P	INT 1 kHz	10 mF	L = 10.000 ± 0.11%	R8	DQ, C1	CGRL

*Tolerance of standard should be added to measurement tolerance, or preferably calibrated standards should be used and their corrections applied.
**Accuracy limited by lack of phase balance.
†From external signal source.
‡Connected in parallel.

limit of no more than 0.01 Ω per step (GR Type 1433-W and -F). Set the PARAMETER switch to C_p, the function switch to AC INTERNAL 1 kHz, and the DQ dial to 0.1 on the High D scale. Balance the bridge by adjustment of the CGRL decade and the external decade resistor. The decade resistor should be set between 1671 Ω and 1512 Ω. Continue resetting the DQ dial and adjusting the external decade resistor within the limits given in Table 6-3 until a null is achieved for each setting. The CGRL decade should not be readjusted. If necessary, reposition the DQ dial on its shaft until the limits of Table 6-3 are met. To reposition the dial, remove the knob and loosen the two set screws on the bushing. Turn the dial to the new position and reinstall the part.

6.4 TROUBLE ANALYSIS.

6.4.1 Preliminary Checks.

If satisfactory measurements are difficult or impossible to obtain, make the following external checks first:

1. Is the unknown component connected correctly?
2. Is the unknown what it is thought to be? Large inductors can look like capacitors at 1 kHz.
3. Are all the panel switches set properly?
4. Are the BIAS and EXT DQ jack switches closed? Insert a plug and short the plug to check.
5. Is the D so high (Q so low) that balance convergence is difficult (see paragraph 2.5)?
6. Is OSC LEVEL control on?
7. Is DET SENS control on?
8. Are the batteries correctly in place?

Table 6-3

DQ DIAL CALIBRATION

DQ Dial High D scale	Decade Resistor Setting Limits
0.1	1512 Ω – 1671 Ω
0.2	756 Ω – 835 Ω
0.5	302.4 Ω – 334.2 Ω
1.0	151.2 Ω – 167.1 Ω
2.0	75.6 Ω – 83.5 Ω
5.0	30.24 Ω – 33.42 Ω
10.0	15.12 Ω – 16.71 Ω
20.0	7.56 Ω – 8.35 Ω
50.0	3.02 Ω – 3.34 Ω*

*This value depends on R3, which may be changed if defective, to give a proper reading.

Table 6-2
RECOMMENDED TEST EQUIPMENT*

Name	Minimum Use Specification		Recommended Equipment** (Federal Stock Number)
Audio Signal Source	Range: 900 - 1100 Hz and 4 kHz Accuracy: ±2 Hz Amplitude: 3 V rms		GR Type 1310 Oscillator
Frequency Meter	Range: 900 - 1100 Hz and 4 kHz Accuracy: ±2 Hz		GR Type 1191 Counter
Electronic Voltmeter	Input Resistance: $\geq$ 20 kΩ Accuracy: ±2% Frequency Range: 900 - 4000 Hz Amplitude Range: 0 - 5 V rms		GR Type 1806 Electronic Voltmeter (6625-832-8956)
Distortion and Noise Meter	Distortion Range: 0 - 10% second-and-third-harmonic distortion Distortion Accuracy: ±5% Frequency Range: 900 - 1100 Hz Amplitude Range: 1.5 - 5 V rms Noise Range: 0 to -58 dBm (0.775 to 0.001 V rms) Noise Accuracy: ±5%		HP Model 331-A Distortion Analyzer
DC Power Supply	Output Voltage: 200 V Accuracy: ±20%. Output Current: 3 mA		Kepco Power Supply Model ABC 200 M
Oscilloscope	Vertical Sensitivity: $\geqslant$50 mV Range: 100 kHz		Tektronix Model 503
	Value	**Accuracy**	
Standard Capacitors	1.0 μF	±0.5%	GR Type 1409-Y (6625-629-1980)
Standard Inductor	100 mH	±0.1%	GR Type 1482-L (6625-556-8584)
Standard Resistors	1 Ω	±0.02%	GR Type 1440-9601
	10 Ω	±0.01%	GR Type 1440-9611
	100 Ω	±0.01%	GR Type 1440-9621
	1 kΩ	±0.01%	GR Type 1440-9631
	10 kΩ	±0.01%	GR Type 1440-9641
	100 kΩ	±0.01%	GR Type 1440-9651
	1 MΩ	±0.01%	GR Type 1440-9661
Adaptor Cable (3 required)	Double plug to telephone plug		GR Type 1560-P95
Patch Cord	Double-plug, right-angle patch cord		GR Type 0274-9892
External Detector	Response at 1 kHz		GR Type 1232 (6625-873-6684)

* Instruments recommended for minimum-performance standards and trouble analysis.
**Or equivalent.

6.4.2 No Meter Indication.

No meter indication, or a low meter indication, may be due to weak or dead batteries, low oscillator output, poor detector sensitivity, or a faulty meter. If the trouble persists in the DC INTERNAL 1 1/2 V position of the function switch (where the oscillator and detector are switched out), the fault is in either the batteries or the meter circuit.

The batteries can be checked by setting the function switch to the BAT CHECK 1 and 2 positions. If the batteries are okay, then the meter is faulty.

The meter can be checked by connection of an external indicator (earphones, ac meter, oscilloscope, etc) to the DET jack.

6.4.3 Noisy or Erratic Balances.

Noisy or erratic balances may be due to surface contamination of the wire-wound DQ control rheostat. Contamination can form if the 1656 Impedance Bridge is idle for an extended period and can be remedied by rotation of the dial several times.

6.4.4 Measurement Errors.

Measurement errors due to faulty bridge-circuit components can be located by making the resistance and capacitance checks of Table 6-1. The inductance measurements will indicate wiring faults in the L bridges but are not required to find out-of-tolerance bridge components because these bridges use the same components as the R and C bridges.

Symptoms and Probable Remedies.

1. When measurements on only one range are in error, the ratio arm R_A is out of tolerance. The reference designator of the resistor is given in Table 6-1.

2. When all resistance measurements are in error (but capacitance measurements are not), R_4 is out of tolerance.

3. When all capacitance measurements (not resistance measurements) are in error, C_1 is out of tolerance.

4. When all measurements are in error, the CGRL decade is out of tolerance (see para. 6.3.1).

6.5 REPAIR NOTES.

6.5.1 Battery Replacement.

The 1656 Impedance Bridge is powered by five D cells. The four cells in the tube will last for over 500 hours' operation with normal use. The fifth cell (B2) (against the inside of the cabinet) will last for a varying amount of time, depending on the size of unknown resistors being measured. The cell will last the longest with unknown resistors of large values.

For a quick check of the four batteries in the tube, use the BAT CHECK 1 position of the generator switch. If the

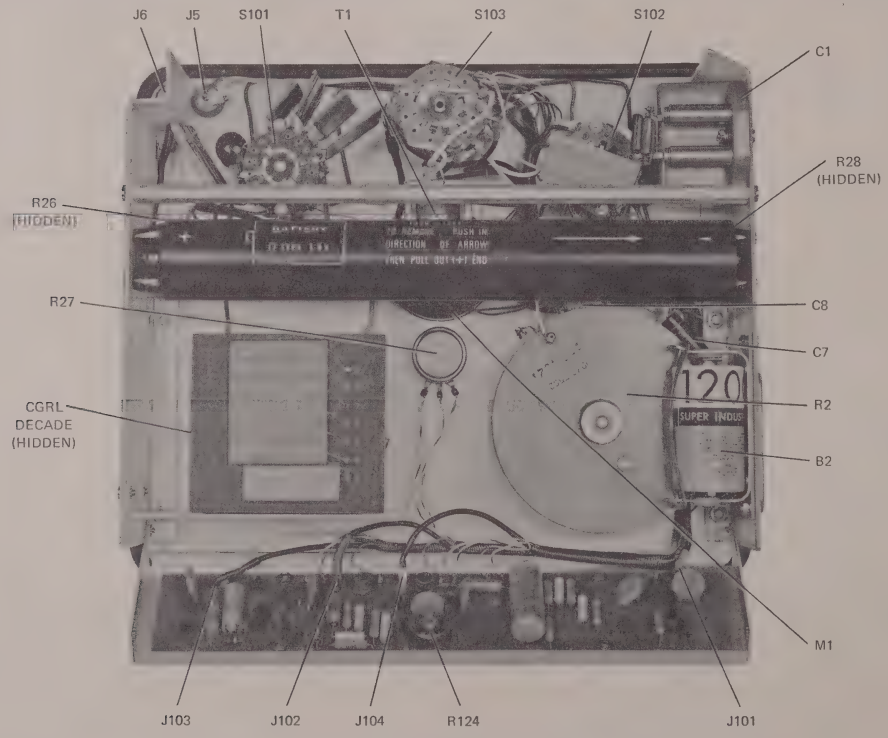


Figure 6-2. Rear interior view of 1656 Bridge.

Table 6-4
OSCILLATOR PERFORMANCE CHECK

Measurement	Remarks
Frequency: 1000 Hz, ±20 Hz	If frequency is incorrect, check the values of R101, R102, R103, C102 and C103.
Output voltage: at least 0.25 V rms	Measure with OSC LEVEL fully clockwise.
Distortion: less than 3%	Low output or excessive distortion may be due to weak batteries (refer to paragraph 6.5.1). If the batteries are normal, R107 or R108 may be clipped out to increase the OSC LEVEL slightly.

meter reads low, replace the batteries being sure to observe the polarity markings on the fiber tube (see para. 1.3). If the meter reads low in the BAT 2 position, replace the battery (B2) in the battery holder on the inside of the cabinet (see para. 1.3).

6.5.2 Etched Circuit Removal.

For access to the etched circuit shown in Figure 6-2, remove the two screws holding the top of the board in place and loosen the two screws at the bottom of the board one turn. Tilt the board out as in Figure 6-2.

6.6 CALIBRATION PROCEDURE.

6.6.1 General.

The few internal adjustments are factory set and normally do not require readjustment. Procedures for readjustment are included here, but should be used only when the operator is reasonably certain that readjustment is necessary.

6.6.2 Equipment Required.

The equipment necessary to perform the following calibration procedures is listed in Table 6-2.

6.6.3 Oscillator.

Set the function switch to AC INTERNAL 1 kHz and the OSC LEVEL control to its full cw position. Use the C_s bridge with nothing connected to the UNKNOWN terminals. The CGRL control should be 0. Perform the checks listed in Table 6-4 by measurement of the output of the oscillator between UNKNOWN HIGH and ground.

If operation is found to be abnormal, perform a stage-by-stage voltage check of the transistors (refer to Table 6-5). Check the battery voltages with the panel meter (BAT CHECK 1 and 2 positions) before reading transistor voltages.

6.6.4 Ac Detector.

To check the detector, set the controls as follows:

PARAMETER	C_s
GENERATOR	AC INT
CGRL	0.000
DQ	Full ccw
MULTIPLIER	1 μF
DET SENS	Full cw

Adjust the OSC LEVEL control so that there is 0.1 V ac between the UNKNOWN HIGH terminal and ground. The meter should read nominally 4 divisions or better.

6.6.5 Dc Detector.

To check the DC Detector sensitivity, short circuit the unknown terminals and set the controls as follows:

PARAMETER	R
GENERATOR	DC INTernal
MULTIPLIER	100 mΩ
DET SENS	Full cw

Balance the bridge with the CGRL decade. Then, change the balance by one digit on the farthest right decade. The meter should move at least 0.3 division. (This is a 10-μV change in detector input voltage.)

If the sensitivity is low it could be due to misadjustment of the FET-chopper capacitance balance. Adjust R124 (on the etched-circuit board) to give a maximum and symmetrical meter deviation when the ZERO DC control is varied over its full range. This should be at least 5 divisions both ways. If this cannot be done, check the detector transistor voltages.

Table 6-5
NOMINAL TRANSISTOR VOLTAGES*

Transistor	Collector (Volts)	Base (Volts)	Emitter (Volts)
Q101	0.64	4.4	5.0
Q102	3.3	0.64	0.0
Q103	0.23	4.7	5.4
Q151	3.85	1.75	1.15
Q152	0.59	0.57	0.0
Q153	5.2	0.59	0.0
Q154	3.7	5.3	6.0
Q155	0.0	0.0	0.0
Q156**	0.0	4.4	0.0
Q157	2.4	3.9	4.5
	SOURCE	DRAIN	GATE
Q121**	0.0	0.1	−1.1 V

*Measurement Conditions (except Q156 and Q121): DET SENS full ccw, OSC LEVEL full cw, GENERATOR switch at AC INTERNAL 1 kHz; measurements made with GR Type 1806 ELECTRONIC VOLTMETER between component and ground; all voltages are positive. Voltages may vary ±10%.

**Measurement Conditions for Q156 and Q121: Same as above except GENERATOR switch at DC INTERNAL 1½ V and PARAMETER switch at R.

6.6.6 Dc Detector — Difference Data.

NOTE

On early production units, there were two controls that required adjustment for this calibration procedure. These units can be identified by the presence of a second potentiometer (R129) beside R124 on the etched-circuit board.

To check the dc detector sensitivity, proceed as follows:

a. Set the controls on the 1656 as follows:

PARAMETER	R
GENERATOR	DC ZERO
MULTIPLIER	100 kΩ
DET SENS	Full cw

b. Connect the oscilloscope to position 304R (grey wire) on the GENERATOR switch (see Figure 7-6) and trigger it at the line frequency. Set the sweep rate at 5 ms.

c. Touch a finger to the UNKNOWN LOW terminal, to introduce 60-Hz pickup.

d. Adjust R129 beside R124 Figure 6-2,for maximum 60-Hz component riding on the 1-kHz signal entering the detector.

Remove finger from UNKNOWN LOW terminal.

e. Alternately adjust R124 and the DC ZERO panel control for minimum 1-kHz signal.

f. Rotate the ZERO DC control over its full range. The pointer of the meter must swing at least 5 divisions on each side of 0.

g. Reset the ZERO DC control for a zero meter reading and change the MULTIPLIER switch setting to 100 mΩ. Observe that the meter indication does not shift by more than 5 divisions.

6.6.7 Final Accuracy/Operational Check.

The measurements given in Table 6-1 are designed to:

1. Check the accuracy of the fixed bridge components.

2. Check the continuity and proper operation of the CGRL PARAMETER, function, and CGRL MULTIPLIER switches and the EXT GEN and UNKNOWN terminals.

3. Recheck the accuracy of the DQ dial and CGRL decade.

Trouble-shooting notes:

1. Since the DQ dial and CGRL decade have been checked, incorrect readings on any range will ordinarily be caused by the ratio resistor, R_A, for that range (R_5 to R_3).

2. If R DC INTERNAL 1 1/2 V readings are incorrect, be sure the NULL meter is zeroed.

6.7 KNOB REMOVAL.

If it should be necessary to remove the knob on a front-panel control, either to replace one that has been damaged or to replace the associated control, proceed as follows:

a. Grasp the knob firmly with the fingers, close into the panel (or the indicator dial, if applicable), and pull the knob straight away from the panel.

CAUTION

Do not pull on the dial to remove a dial/knob assembly. Always remove the knob first. To avoid damage to the knob and other parts of the control, do not pry the knob loose with a screwdriver or similar flat tool, and do not attempt to twist the knob from the dial.

b. Observe the position of the setscrew in the bushing, with respect to any panel markings (or at the full ccw position of a continuous control).

c. Release the setscrew and pull the bushing off the shaft. Use a No. 10 Allen wrench for the CGRL PARAMETER and MULTIPLIER bushings and a No. ¼ for the DQ bushings.

d. Remove and retain the black nylon thrust washer, behind the dial/knob assembly, as appropriate.

NOTE

To separate the bushing from the knob, if for any reason they should be combined off the instrument, drive a machine tap a turn or two into the bushing for a sufficient grip, for easy separation.

6.8 KNOB INSTALLATION.

To install a knob assembly on the control shaft:

a. Place the black nylon thrust washer over the control shaft, if appropriate.

b. Mount the bushing on the shaft, using a small slotted piece of wrapping paper as a shim for adequate panel clearance.

c. Orient the setscrew on the bushing with respect to the panel-marking index and lock the setscrew with the appropriate key wrench (paragraph 6.7c).

NOTE

Make sure that the end of the shaft does not protrude through the bushing or the knob won't bottom properly.

d. Place the knob on the bushing with the retention spring opposite the setscrew.

e. Push the knob in until it bottoms and pull it slightly to check that the retention spring is seated in the groove in the bushing.

NOTE

If the retention spring in the knob comes loose, reinstall it in the interior notch that has the thin slit in the side wall. It will not mount in the other notch.

Parts Lists and Diagrams—Section 7

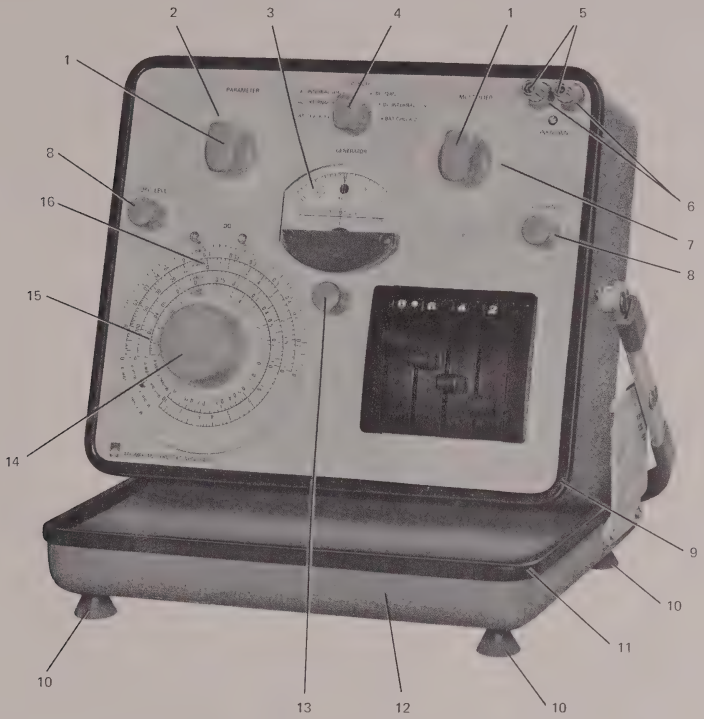


Figure 7-1. Replaceable mechanical parts.

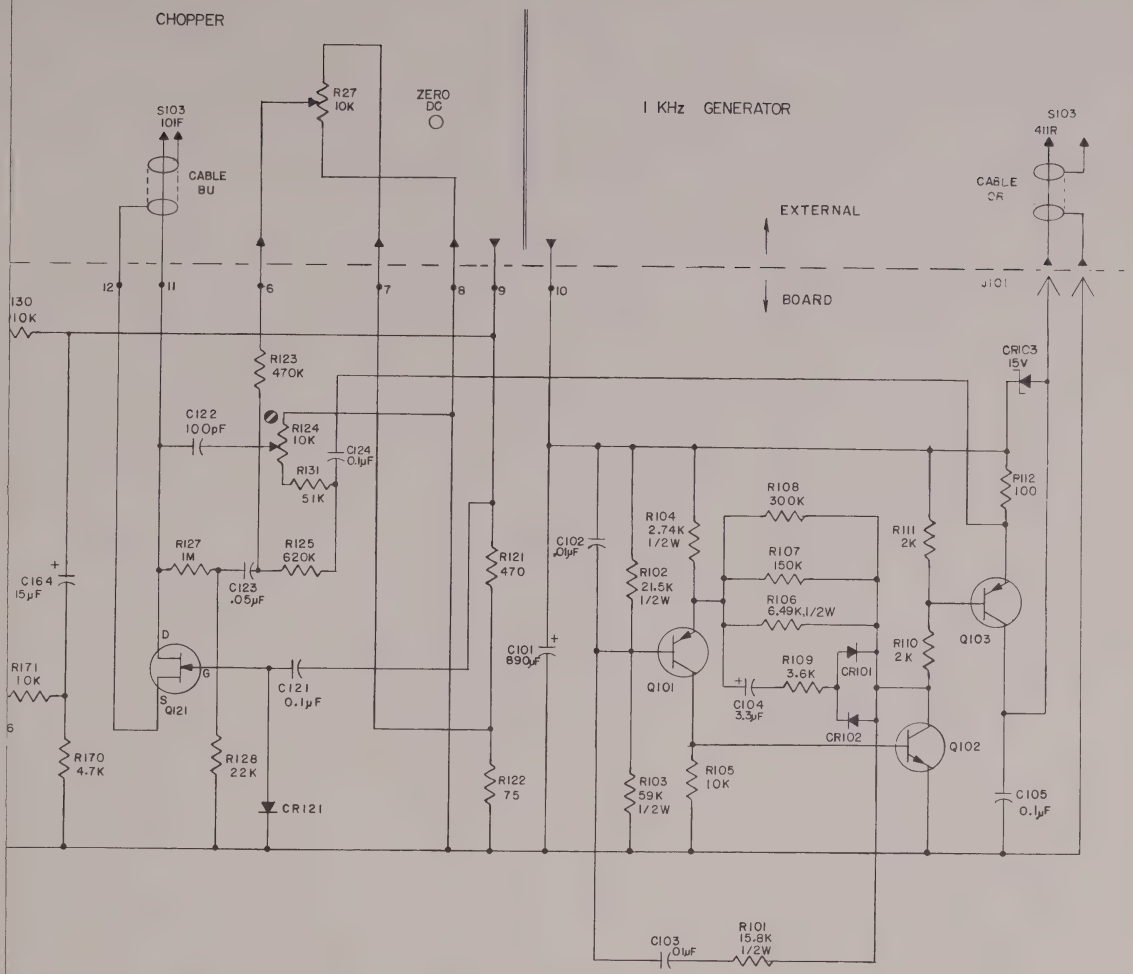
MECHANICAL PARTS LIST

Qty	Figure Reference	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
2	1	Knob asm., PARAMETER; MULTIPLIER, including retainer 5220-5401	5500-5420	24655	5500-5420	
1	2	Dial asm., PARAMETER	1650-1240	24655	1650-1240	
1	3	Meter cover, plastic, Honeywell	5720-3713	24655	5720-3713	
1	4	Knob asm., GENERATOR, including retainer 5220-5402	5500-5321	24655	5500-5321	
2	5	Binding post, J5, UNKNOWN LOW; J6, UNKNOWN HIGH	0938-3000	24655	0938-3000	5940-075-9617
2	6	Insulators	0938-7130	24655	0938-7130	
1	7	Dial asm., MULTIPLIER	1650-1250	24655	1650-1250	
2	8	Knob asm., DET SENS; OSC LEVEL, including retainer 5220-5402	5520-5221	24655	5520-5221	
1	9	Rubber gasket around edge of panel	5168-1410	24655	5168-1410	
4	10	Rubber foot for cover asm.	5260-0760	24655	5260-0760	
1	11	Rubber gasket around cover asm.	5168-0680	24655	5168-0680	
1	12	Cabinet asm., flip-tilt, including gasket	4182-2004	24655	4182-2004	
1	13	Knob asm., ZERO DC, including retainer 5220-5402	5520-5220	24655	5520-5220	
1	14	Knob asm., DQ, including retainer 5220-5401	5520-5520	24655	5520-5520	
1	15	Dial asm., DQ	1650-1070	24655	1650-1070	
1	16	Indicator	1650-7161	24655	1650-7161	

ELECTRICAL PARTS LIST

Etched-circuit Board (P/N 1656-4700)

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
CAPACITORS					
C101	Electrolytic, 890 µF +150-10% 10 V	4450-6010	37942	TT, 890 µF +150-10%	
C102 and					
C103	Mylar, 0.01 µF ±1% 100 V	4860-7752	84411	663UW, 0.01 µF 1%	
C104	Tantalum, 3.3 µF ±10%, 15 V	4450-4601	01295	15335C2	
C105	Ceramic, 0.1 µF +80-20% 100 V	4403-4100	80183	CC63, 0.1 µF +80-20%	5910-974-5699
C121	Ceramic, 0.1 µF +80-20% 100 V	4403-4100	80183	CC63, 0.1 µF +80-20%	5910-974-5699
C122	Ceramic, 100 pF ±5% 500 V	4404-1105	72982	831, 100 pF 5%	
C123	Ceramic, 0.5 µF +80-20% 100 V	4403-3500	01121	40-503W	5910-883-7321
C124	Ceramic, 0.1 µF +80-20% 100 V	4403-4100	80183	CC63, 0.1 µF +80-20%	5910-974-5699
C151	Ceramic, 0.1 µF +80-20% 100 V	4403-4100	80183	CC63, 0.1 µF +80-20%	5910-974-5699
C152	Electrolytic, 15 µF +150-10% 15 V	4450-3700	37942	TT, 15 µF +150-10%	
C153	Electrolytic, 200 µF +150-10% 6 V	4450-2610	37942	TT, 200 µF +150-10%	5910-945-1836
C154	Electrolytic, 10 µF +150-10% 25 V	4450-3800	56289	301D106G025BB4M1	5910-952-8658
C155	Ceramic, 68 pF ±5% 500 V	4404-0685	72982	831, 68 pF 5%	
C156 and					
C157	Mylar, 0.01 µF ±1% 100 V	4860-7752	84411	663UW, 0.01 µF 1%	
C158	Mylar, 0.01 µF ±1% 100 V	4860-7853	84411	663UW, 0.01 µF 1%	
C159	Ceramic, 10 pF ±5% 500 V NPO	4410-0105	72982	811, 10 pF ±5%	
C160	Tantalum, 3.3 µF ±10% 15 V	4450-4601	01295	15335C2	
C161	Ceramic, +80-20% 100 V	4403-3500	01121	40-503W	5910-883-7321
C162	Ceramic, 100 pF ±5% 500 V	4404-1105	72982	831, 100 pF 5%	
C163	Tantalum, 3.3 µF ±10% 15 V	4450-4601	01295	15335C2	
C164	Electrolytic, 15 µF +150-10% 15 V	4450-3700	37942	TT, 15 µF +150-10%	
DIODES					
CR101 and					
CR102	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
CR103	Type 1N965B	6083-1015	07910	1N965B	5960-877-6192
*CR121	Type 1N995	6082-1002	80368	1N995	5961-893-6762
CR151 and					
CR152	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
RESISTORS					
R101	Film, 15.8 kΩ ±1% 1/2 W	6451-2158	75042	CEC-TO, 15.8 kΩ 1%	
R102	Film, 21.5 kΩ ±1%	6451-2215	75042	CEC-TO, 21.5 kΩ 1%	
R103	Film, 59 k kΩ ±1%	6450-2590	75042	CEC, 59 kΩ 1%	
R104	Film, 2.74 kΩ ±1%	6450-1274	75042	CEC, 2.74 kΩ 1%	
R105	Comp., 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ 10%	
R106	Film, 6.99 kΩ ±1% 1/4 W	6450-1649	75042	CEC, 6.99 kΩ 1%	
R107	Comp., 150 kΩ ±10% 1/4 W	6099-4159	75042	BTS, 150 kΩ 10%	
R108	Comp., 300 kΩ ±5% 1/4 W	6099-4305	75042	BTS, 300 kΩ 5%	5905-681-8854
R109	Comp., 3.6 kΩ ±5% 1/4 W	6099-2365	75042	BTS, 3.6 kΩ 5%	5905-577-0627
R110 and					
R111	Comp., 2 kΩ ±5% 1/4 W	6099-2205	75042	BTS, 2 kΩ 5%	5905-686-3370



RESISTANCE IS IN OHMS, K=10^3, M=10^6
CAPACITANCE IS IN FARADS, μ=10^{-6}, p=10^{-12}
VOLTAGES EXPLAINED IN INSTRUCTION BOOK SERVICE NOTES
PANEL CONTROL ⊏⊐ =REAR CONTROL
⊘=SCREWDRIVER CONTROL WT=WIRE TIE TP=TEST POINT
COMPLETE REFERENCE DESIGNATION INCLUDES SUBASSEMBLY LETTER, C-R1, B-R1, ETC.

404F SWITCH NUMBERING
FRONT, REAR
CONTACTS, FIRST CONTACT CW FROM STRUT SCREW ABOVE KEY IS .01.
SECTION. SECTION NEAREST PANEL IS 1.
ROTORS SHOWN CCW

CONNECTIONS
OUTPUT LEAVES SUBASSEMBLY
INPUT FROM DIFFERENT SUBASSEMBLY
OUTPUT REMAINS ON SUBASSEMBLY
INPUT FROM SAME SUBASSEMBLY

Figure 7-3. Schematic diagram of the internal oscillator and detector.

ELECTRICAL PARTS LIST

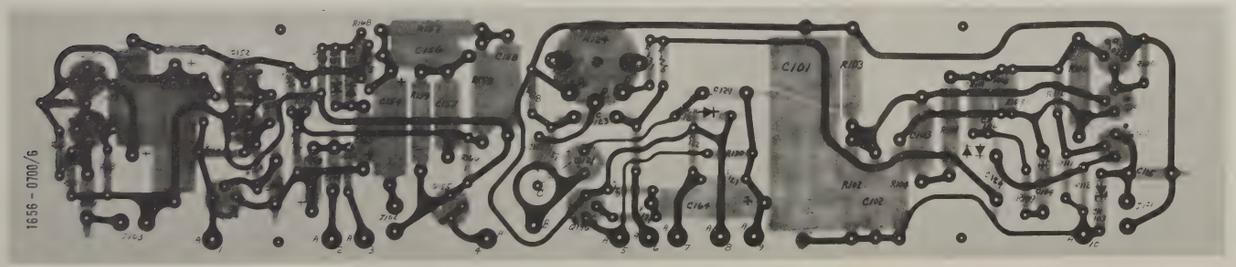
Etched-circuit Board (P/N 1656-4700)

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
CAPACITORS					
C101	Electrolytic, 890 µF +150-10% 10 V	4450-6010	37942	TT, 890 µF +150-10%	
C102 and					
C103	Mylar, 0.01 µF ±1% 100 V	4860-7752	84411	663UW, 0.01 µF 1%	
C104	Tantalum, 3.3 µF ±10%, 15 V	4450-4601	01295	15335C2	
C105	Ceramic, 0.1 µF +80-20% 100 V	4403-4100	80183	CC63, 0.1 µF +80-20%	5910-974-5699
C121	Ceramic, 0.1 µF +80-20% 100 V	4403-4100	80183	CC63, 0.1 µF +80-20%	5910-974-5699
C122	Ceramic, 100 pF ±5% 500 V	4404-1105	72982	831, 100 pF 5%	
C123	Ceramic, 0.5 µF +80-20% 100 V	4403-3500	01121	40-503W	5910-883-7321
C124	Ceramic, 0.1 µF +80-20% 100 V	4403-4100	80183	CC63, 0.1 µF +80-20%	5910-974-5699
C151	Ceramic, 0.1 µF +80-20% 100 V	4403-4100	80183	CC63, 0.1 µF +80-20%	5910-974-5699
C152	Electrolytic, 15 µF +150-10% 15 V	4450-3700	37942	TT, 15 µF +150-10%	
C153	Electrolytic, 200 µF +150-10% 6 V	4450-2610	37942	TT, 200 µF +150-10%	5910-945-1836
C154	Electrolytic, 10 µF +150-10% 25 V	4450-3800	56289	301D106G025BB4M1	5910-952-8658
C155	Ceramic, 68 pF ±5% 500 V	4404-0685	72982	831, 68 pF 5%	
C156 and					
C157	Mylar, 0.01 µF ±1% 100 V	4860-7752	84411	663UW, 0.01 µF 1%	
C158	Mylar, 0.01 µF ±1% 100 V	4860-7853	84411	663UW, 0.01 µF 1%	
C159	Ceramic, 10 pF ±5% 500 V NPO	4410-0105	72982	811, 10 pF ±5%	
C160	Tantalum, 3.3 µF ±10% 15 V	4450-4601	01295	15335C2	
C161	Ceramic, +80-20% 100 V	4403-3500	01121	40-503W	5910-883-7321
C162	Ceramic, 100 pF ±5% 500 V	4404-1105	72982	831, 100 pF 5%	
C163	Tantalum, 3.3 µF ±10% 15 V	4450-4601	01295	15335C2	
C164	Electrolytic, 15 µF +150-10% 15 V	4450-3700	37942	TT, 15 µF +150-10%	
DIODES					
CR101 and					
CR102	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
CR103	Type 1N965B	6083-1015	07910	1N965B	5960-877-6192
*CR121	Type 1N995	6082-1002	80368	1N995	5961-893-6762
CR151 and					
CR152	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
RESISTORS					
R101	Film, 15.8 kΩ ±1% 1/2 W	6451-2158	75042	CEC-TO, 15.8 kΩ 1%	
R102	Film, 21.5 kΩ ±1%	6451-2215	75042	CEC-TO, 21.5 kΩ 1%	
R103	Film, 59 k kΩ ±1%	6450-2590	75042	CEC, 59 kΩ 1%	
R104	Film, 2.74 kΩ ±1%	6450-1274	75042	CEC, 2.74 kΩ 1%	
R105	Comp., 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ 10%	
R106	Film, 6.99 kΩ ±1% 1/4 W	6450-1649	75042	CEC, 6.99 kΩ 1%	
R107	Comp., 150 kΩ ±10% 1/4 W	6099-4159	75042	BTS, 150 kΩ 10%	
R108	Comp., 300 kΩ ±5% 1/4 W	6099-4305	75042	BTS, 300 kΩ 5%	5905-681-8854
R109	Comp., 3.6 kΩ ±5% 1/4 W	6099-2365	75042	BTS, 3.6 kΩ 5%	5905-577-0627
R110 and					
R111	Comp., 2 kΩ ±5% 1/4 W	6099-2205	75042	BTS, 2 kΩ 5%	5905-686-3370

ELECTRICAL PARTS LIST (cont)

Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
RESISTORS (Cont)					
R112	Comp., 100 Ω ±5% 1/4 W	6099-1105	75042	BTS, 100 Ω 5%	
†R121	Comp., 470 Ω ±5% 1/4 W	6099-1475	75042	BTS, 620 Ω 5%	5905-801-6998
R122	Comp., 75 Ω ±5% 1/4 W	6099-0755	75042	BTS, 75 Ω 5%	
R123	Comp., 470 kΩ ±10% 1/4 W	6099-4479	75042	BTS, 470 kΩ 10%	
R124	Pot. Wire wound, 10 kΩ ±10%	6056-0144	11236	115, 10 kΩ 10%	
R125	Comp., 620 kΩ ±5% 1/4 W	6099-4625	75042	BTS, 620 kΩ 5%	
R128	Comp., 22 kΩ ±10% 1/4 W	6099-3229	75042	BTS, 22 kΩ 10%	
R130	Comp., 910 kΩ ±5% 1/4 W	6099-4915	75042	BTS, 910 kΩ 5%	
R138	Comp., 51 kΩ ±5% 1/4 W	6099-3515	75042	BTS, 51 kΩ 5%	5905-682-4103
R151 and					
R152	Comp., 1 MΩ ±10% 1/4 W, E127	6099-5109	75042	BTS, 1 MΩ 10%	
R153	Comp., 5.1 kΩ ±5% 1/4 W	6099-2515	75042	BTS, 5.1 kΩ 5%	5905-683-2241
R154	Comp., 2.4 kΩ ±5% 1/4 W	6099-2245	75042	BTS, 2.4 kΩ 5%	5905-683-7724
R155	Comp., 15 kΩ ±10% 1/4 W	6099-3159	75042	BTS, 15 kΩ 10%	
R156	Comp., 1 MΩ ±10% 1/4 W E127	6099-5109	75042	BTS, 1 MΩ 10%	
R157 and					
R158	Film, 16.9 kΩ ±1%	6450-2169	75042	CEC, 16.9 kΩ 1%	
R159	Film, 6.65 kΩ ±1%	6450-1665	75042	CEC, 6.6 kΩ 1%	5905-581-4995
R160	Comp., 39 kΩ ±10% 1/4 W	6099-3399	75042	BTS, 39 kΩ 5%	
R161	Comp., 4.7 kΩ ±10% 1/4 W	6099-2479	75042	BTS, 4.7 kΩ 10%	
R163	Comp., 4.7 kΩ ±10% 1/4 W	6099-2479	75042	BTS, 4.7 kΩ 10%	
R164	Comp., 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ 10%	
R165	Comp., 2 kΩ ±5% 1/4 W	6099-2205	75042	BTS, 2 kΩ 5%	5905-686-3370
R166	Comp., 680 Ω ±5% 1/4 W	6099-1685	75042	BTS, 680 Ω 5%	
R167	Comp., 1 kΩ ±10% 1/4 W	6099-2109	75042	BTS, 1 kΩ 10%	5905-681-6462
R168	Comp., 100 kΩ ±10% 1/4 W	6099-4109	75042	BTS, 100 kΩ 10%	
R169	Comp., 1 kΩ ±10% 1/4 W	6099-2109	75042	BTS, 1 kΩ 10%	5905-681-6462
R170	Comp., 47 kΩ ±10% 1/4 W	6099-2479	75042	BTS, 4.7 kΩ 10%	
R171	Comp., 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ 10%	
R172	Comp., 6.2 kΩ ±5% 1/4 W	6099-2625	75042	BTS, 6.2 kΩ 5%	5905-682-4100
R173	Comp., 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ 10%	
TRANSISTORS					
Q101	Type 2N3905	8210-1114	04713	2N3905	
Q102	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749
Q103	Type 2N3905	8210-1114	04713	2N3905	
†Q121	Type E101	8210-1187	17856	E101	
Q151 thru					
Q153	Type 2N3414	8210-1047	24454	2N3414	5961-989-2749
Q154	Type 2N3905	8210-1114	04713	2N3905	
Q155	Type 2N1302	8210-1018	96214	2N1302	5960-086-0039
Q156	Type 1N1303	8210-1019	96214	2N1303	
Q157	Type 2N3905	8210-1114	04713	2N3905	

*Omitted in early production
‡Gate bias on Q121 adjustable with a 10-kΩ pot. (R129), in series with a 220-kΩ resistor, R126, on early production units.
†R121 = 620 Ω, R122 = 100 Ω and R131 = 100 kΩ, in early production.



NOTE: The board is shown foil-side up. The number appearing on the foil side is *not* the part number. The dot on the foil at the transistor socket indicates the collector lead.

Figure 7-2. Etched circuit assembly (P/N 1656-4700)

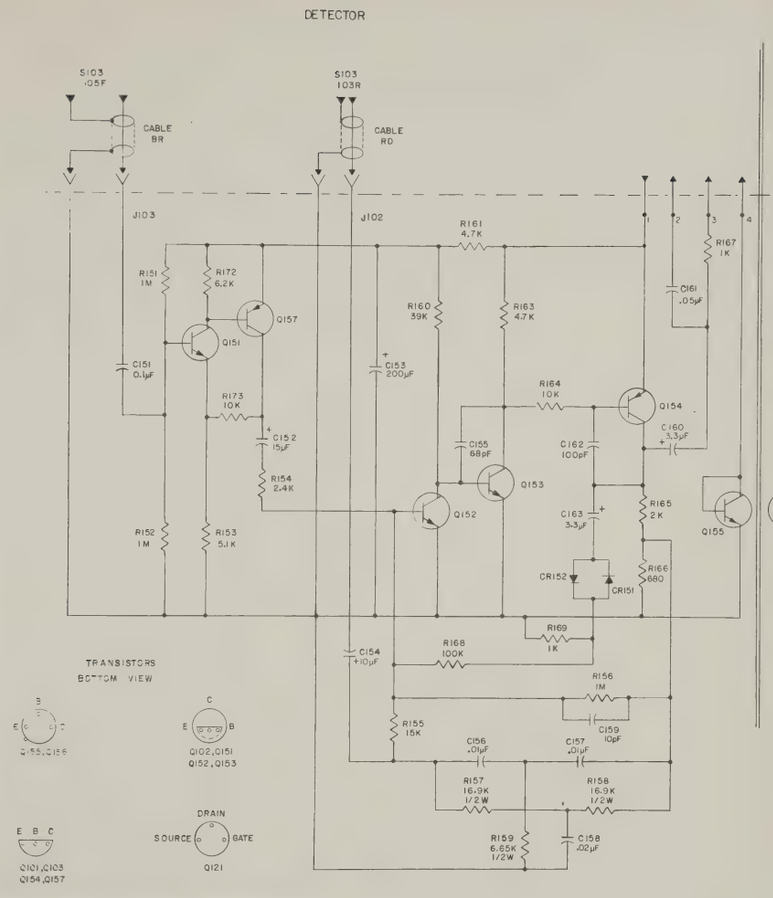
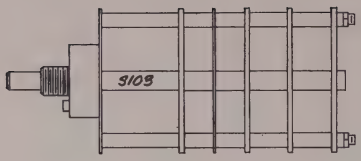


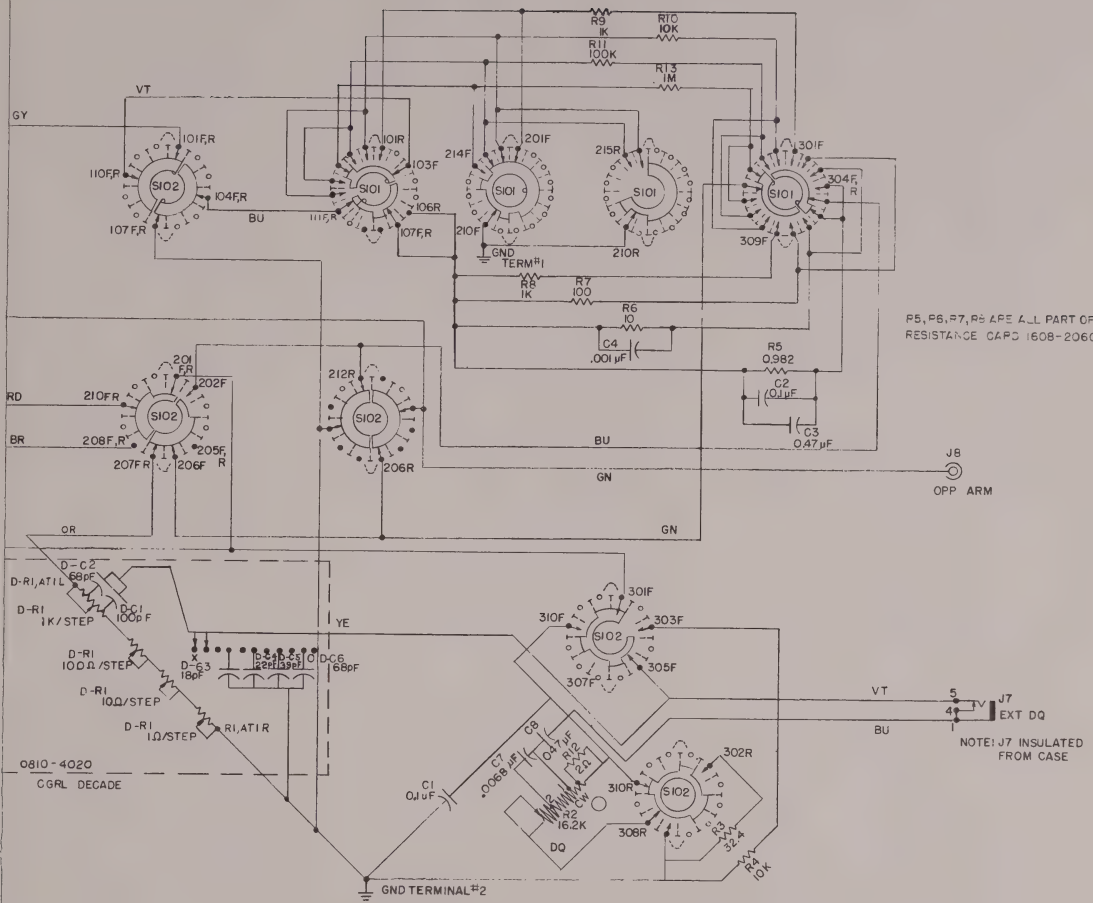
Figure 7-3. Schematic diagram of the internal oscillator and detector.

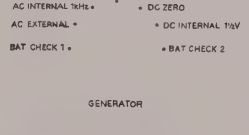


CONNECTIONS

S103, 101F	TO	S103, 103F	BY	R20
S103, 102F	TO	S103, 106F	BY	C6
S103, 103R	TO	S103, 110R	BY	R29
S103, 108F	TO	S103, 109F	BY	R21
S103, 109F	TO	S103, 112F	BY	C5
S103, 204F	TO	S103, 205F	BY	R23
S103, 205F	TO	S103, 305F	BY	R22
S103, 112F&R	TO	S103, 107R		
S103, 307F	TO	S103, 409F	BY	R24
S103, 312F	TO	S103, 312R		
S103, 401R	TO	S103, 406F & L		
S103, 406F	TO	S103, 409F	BY	R25
S103, 201F&R	TO	S103, 303F	BY	C9

Figure 7-6. S103, GENERATOR, switch assembly.





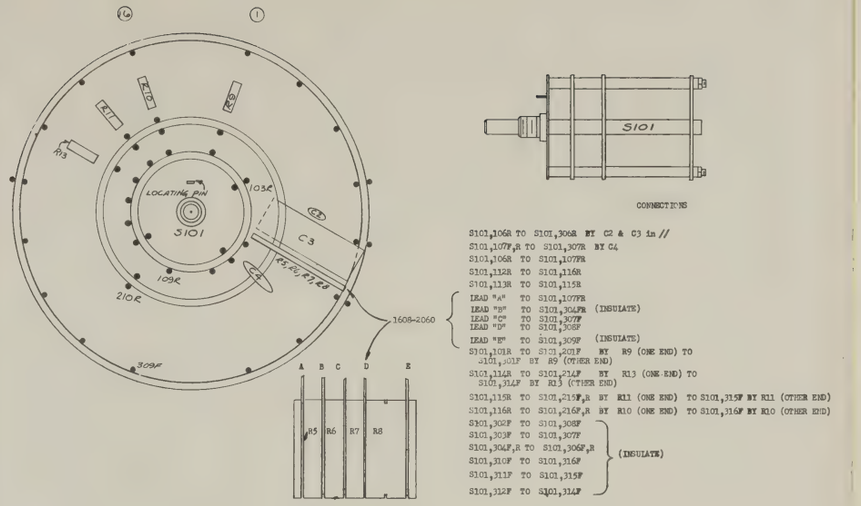
Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

RESISTANCE IS IN OHMS, K=10³, M=10⁶
CAPACITANCE IS IN FARADS, µ=10⁻⁶, p=10⁻¹²
VOLTAGES EXPLAINED IN INSTRUCTION BOOK SERVICE NOTES
PANEL CONTROL
REAR CONTROL
SCREWDRIVER CONTROL WT=WIRE TIE TP=TEST POINT
COMPLETE REFERENCE DESIGNATION INCLUDES SUBASSEMBLY LETTER, C-R1, B-R1, ETC.
4 0 4 F
SWITCH NUMBERING
FRONT, REAR
CONTACTS, FIRST CONTACT CW FROM STRUT SCREW ABOVE KEY IS .01.
SECTION, SECTION NEAREST PANEL IS 1.
ROTORS SHOWN CCW
CONNECTIONS
OUTPUT LEAVES SUBASSEMBLY
INPUT FROM DIFFERENT SUBASSEMBLY
OUTPUT REMAINS ON SUBASSEMBLY
INPUT FROM SAME SUBASSEMBLY

Figure 7-9. Schematic diagram of 1656 Impedance Bridge.

ELECTRICAL PARTS LIST

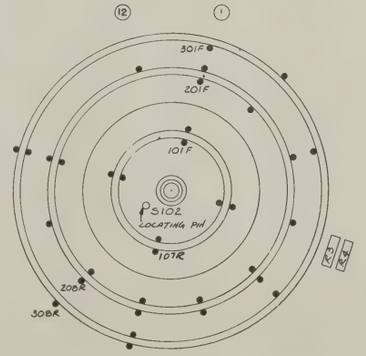
Ref Des	Description	GR Part No.	Fed Mfg Code	Mfg Part No.	Fed Stock No.
CAPACITORS					
C1		0505-4980	24655	0505-4980	
C3	Plastic, .47 µF ±10%	5020-1200	80183	109P47492	
C4	Ceramic, 1000 pF ±10%	4406-2108	72982	811, .001 µF 10%	5910-928-1476
C5	Plastic, .47 µF ±10%	4860-8248	84411	663UW, .47 µF 10%	
C6	Oil impregnated, .10 µF ±10%	4510-4500	56289	73P10496	5910-979-3360
C7	Plastic	4863-2689	56289	194P68294	
C9	Ceramic, 1000 pF +80-20%	4404-2109	72982	831, .001 µF +80-20%	5910-075-9607
RESISTORS					
	Decade Resistor assembly	0810-4020	24655	0810-4020	
R2	Potentiometer, wire-wound	0977-4021	24655	0977-4021	
R3	Film, 32.4 kΩ ±.1%	6450-9324	75042	CEC, 32.4 kΩ .1%	
R4	Wire Wound, 10 kΩ ±.02%	6983-5000	24655	6983-5000	
R5 thru R8	Resistance Unit	1608-2060	24655	1608-2060	
R9	Wire Wound, 1 kΩ ±.02%	6983-4000	24655	6983-4000	
R10	Wire Wound, 10 kΩ ±.02%	6983-5000	24655	6983-5000	
R11	Wire Wound, 100 kΩ ±.02%	6983-6000	24655	6983-6000	
R13	Wire Wound, 1 MΩ ±1.5%	6984-7001	24655	6984-7001	
R14	Comp., 3.9 kΩ ±5%	6100-2395	01121	RC20GF392J	5905-279-3505
R20,R21	Comp., 47 kΩ ±10%	6099-3479	75042	BTS, 47 kΩ 10%	5905-683-2246
R22	Comp., 39 kΩ ±5%	6099-3395	75042	BTS, 39 kΩ 5%	5905-686-3358
R23	Comp., 15 Ω ±10%	6099-0159	75042	BTS, 15 Ω 10%	
R24	Film, 164 kΩ ±1%	6350-3164	75042	CEB, 164 kΩ 1%	
R25	Comp., 750 Ω ±5%	6099-1755	75042	BTS, 750 Ω 5%	
R26	Pot. Comp., 100 kΩ ±10%	6020-0700	01121	JU, 100 kΩ 10%	
R27	Pot. Comp., 10 kΩ ±10%	6000-0600	01121	JU, 10 kΩ 10%	
R28	Pot. Comp., 2.5 kΩ ±10%	6000-0400	12697	53MS, 2.5 kΩ 10%	5905-792-3163
R29	Comp., 47 kΩ ±10%	6099-3479	75042	BTS, 47 kΩ 10%	5905-683-2246
DIODES					
CR1, CR2	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
SWITCHES					
S101	Rotary Wafer	7890-4680	24655	7890-4680	
S102	Rotary Wafer	7890-4690	24655	7890-4690	
S103	Rotary Wafer	7890-4430	24655	7890-4430	
CONNECTORS					
J1, J2	Bushing	4150-3200	24655	4150-3200	
J3	Phone Jack	4260-1030	82389	#111	5935-786-5775
J4	Phone Jack	4260-1041	82389	N112A	
J5, J6	Binding post	0938-3000	24655	0938-3000	
J7	Phone Jack	4260-1041	82389	N112A	
J8	Bushing	4150-3200	24655	4150-3200	
TRANSFORMERS					
T1	Transformer asm.	0746-4540	24655	0746-4540	
B1	Tube asm.	1650-1261	24655	1650-1261	
METERS					
M1	ME-3T	5730-1431	80022	ME-3T	

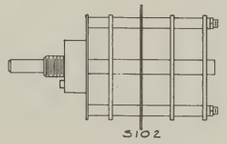


CONNECTIONS

S101,106R TO S101,306R BY C2 & C3 in //
S101,107F,R TO S101,307R BY C4
S101,106R TO S101,107FR
S101,112R TO S101,116R
S101,113R TO S101,115R
LEAD "A" TO S101,107FR
LEAD "B" TO S101,304FR (INSULATE)
LEAD "C" TO S101,307F
LEAD "D" TO S101,308F
LEAD "E" TO S101,309F (INSULATE)
S101,101R TO S101,201F BY R9 (ONE END) TO S101,201F BY R9 (OTHER END)
S101,114R TO S101,214F BY R13 (ONE END) TO S101,314F BY R13 (OTHER END)
S101,115R TO S101,215F,R BY R11 (ONE END) TO S101,315F BY R11 (OTHER END)
S101,116R TO S101,216F,R BY R10 (ONE END) TO S101,316F BY R10 (OTHER END)
S101,302F TO S101,308F
S101,303F TO S101,307F
S101,304F,R TO S101,306F,R
S101,310F TO S101,316F
S101,311F TO S101,315F
S101,312F TO S101,314F
(INSULATE)

Figure 7-4. S101, MULTIPLIER switch, assembly.

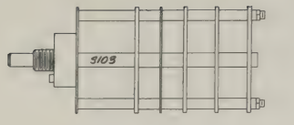




CONNECTIONS

S102, 202F TO S102, 212R
S102, 302R TO S102, 307R BY R3
S102, 303F TO S102, 307R BY R4
S102, 107F,R TO S102, 209R TO S102, 307F,R
S102, 301F TO S102, 201F,R

Figure 7-5. S102, PARAMETER, switch assembly.



CONNECTIONS

S103, 101F	TO	S103, 109F	BY	C20
S103, 102F	TO	S103, 106F	BY	C6
S103, 103R	TO	S103, 110R	BY	C19
S103, 108F	TO	S103, 109F	BY	R21
S103, 109F	TO	S103, 113F	BY	C5
S103, 204F	TO	S103, 205F	BY	R23
S103, 205F	TO	S103, 305F	BY	R22
S103, 113F,R	TO	S103, 107R		
S103, 303F	TO	S103, 409F	BY	R24
S103, 315F	TO	S103, 516R		
S103, 401R	TO	S103, 406F,R		
S103, 406F	TO	S103, 409F	BY	R25
S103, 201F,R	TO	S103, 303F	BY	C9

Figure 7-6. S103, GENERATOR, switch assembly.

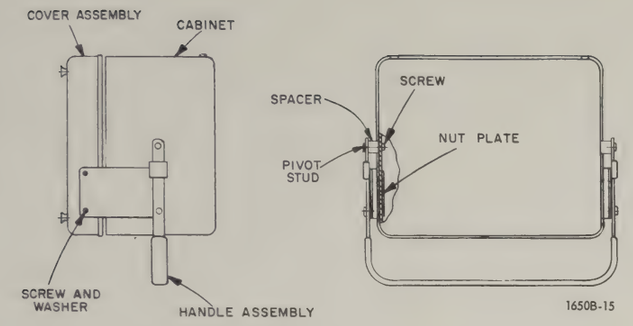


Figure 7-7. Complete cabinet assembly (P/N 4182-2004).

Name	GR Part No.	Name	GR Part No.
Cabinet	4182-8210	Cover Assembly	4170-2066
Spacer	4170-0700	Nut Plate	4170-1350
Pivot Stud	4170-1000	Screw	7080-1000
Screw*	7090-0075	Washer	8040-2450
Handle Assembly	5361-2002		

*Tighten 1/4 - 28 screws to 45-55 in. lbs torque.
**Bend mounting plate to give 1/32 to 1/16 spacing, both sides.

Name	GR Part No.	Name	GR Part No.
Mounting Plate (Instruction Plate)	7860-5770	Mounting Plate (Name Plate)	7864-8200
Stud	4170-1100	Washer	8140-0105
Slide	4170-1270	Slide Washer	4170-7030
Handle	5360-1013		

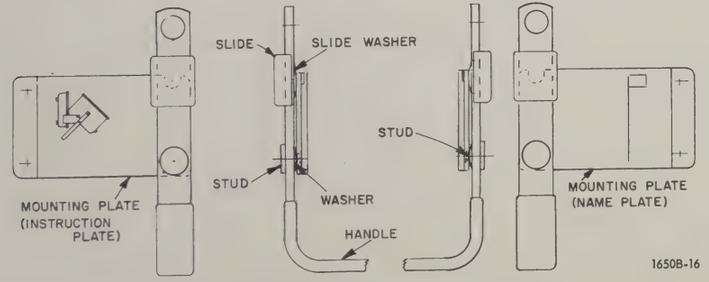


Figure 7-8. Complete handle and mounting plate assembly (P/N 5361-2004).

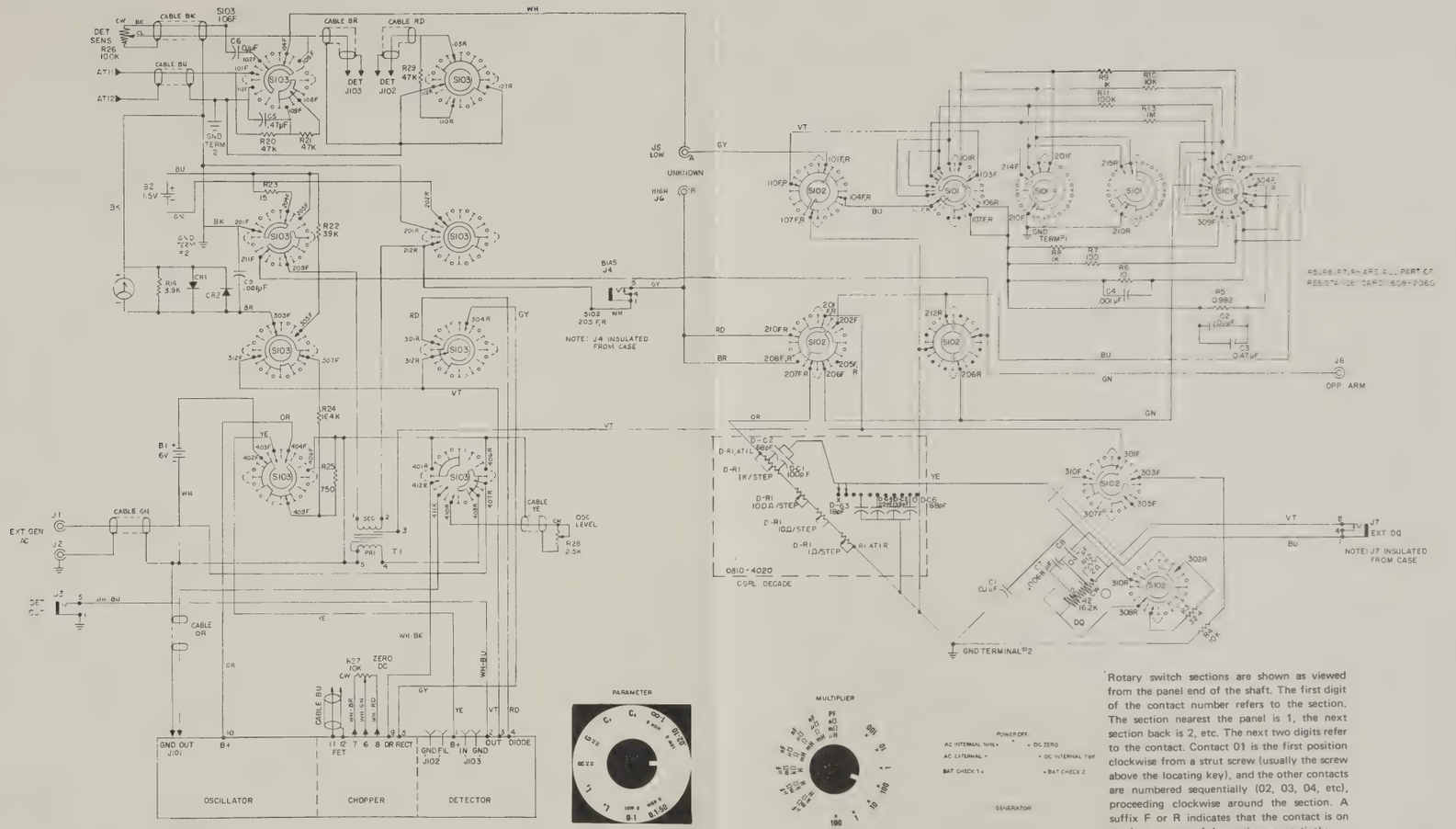

OSCILLATOR
CHOPPER
DETECTOR
LEGEND FOR SI02
LEGEND FOR SI01
LEGEND FOR SI03
Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

Figure 7-9. Schematic diagram of 1656 Impedance Bridge.

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From Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) as supplemented through August, 1968.

Code	Manufacturer
00192	Jones Mfg. Co, Chicago, Illinois
00194	Walsco Electronics Corp, L.A., Calif.
00434	Schweber Electronics, Westburg, L.I., N.Y.
00656	Aerovox Corp, New Bedford, Mass.
01009	Alden Products Co, Brockton, Mass.
01121	Allen-Bradley, Co, Milwaukee, Wisc.
01236	Leeds Radio Company, N.Y.
01255	Litton Industries Inc, Beverly Hills, Calif.
01295	Texas Instruments, Inc, Dallas, Texas
02114	Ferroxcube Corp, Saugerties, N.Y. 12477
02606	Fenwal Lab Inc, Morton Grove, Ill.
02660	Amphenol Electron Corp, Broadview, Ill.
02768	Fastex, Des Plaines, Ill. 60016
03042	Carter Ink Co., Camb. Mass. 02142
03508	G.E. Semicon Prod, Syracuse, N.Y. 13201
03636	Grayburne, Yonkers, N.Y. 10701
03888	Pyrofilm Resistor Co, Cedar Knolls, N.J.
03911	Clairex Corp, New York, N.Y. 10001
04009	Arrow-Hart & Hegeman, Hart., Conn. 06106
04643	Digitronics Corp., Albertson, N.Y. 11507
04713	Motorola, Phoenix, Ariz. 85008
05170	Engr'd Electronics, Santa Ana, Calif. 92702
05624	Barber-Colman Co, Rockford, Ill. 61101
05748	Barnes Mfg. Co., Mansfield, O. 44901
05820	Wakefield Eng, Inc, Wakefield, Mass. 01880
06743	Clevite Corp., Cleveland, O. 44110
07126	Digitron Co, Pasadena, Calif.
07127	Eagle Signal (E.W. Bliss Co.), Baraboo, Wisc.
07261	Avnet Corp, Culver City, Calif. 90230
07263	Fairchild Camera, Mountain View, Calif.
07387	Birtcher Corp, No. Los Angeles, Calif.
07595	Amer Semicond, Arlington Hts, Ill. 60004
07828	Bodine Corp, Bridgeport, Conn. 06605
07829	Bodine Electric Co, Chicago, Ill. 60618
07910	Cont Device Corp, Hawthorne, Calif.
07983	State Labs Inc, N.Y., N.Y. 10003
07999	Borg Inst., Delavan, Wisc. 53115
08730	Vernaline Prod Co., Franklin Lakes, N.J.
09213	G.E. Semiconductor, Buffalo, N.Y.
09408	Star-Tronics Inc, Georgetown, Mass. 01830
09823	Burgess Battery Co, Freeport, Ill.
09922	Burndy Corp, Norwalk, Conn. 06852
11236	C.T.S. of Berne, Inc, Berne, Ind. 46711
11599	Chandler Evans Corp, W. Hartford, Conn.
12040	National Semiconductor, Danbury, Conn.
12498	Crystalonics, Cambridge, Mass. 02140
12672	RCA, Woodbridge, N.J.
12697	Clarostat Mfg Co, Inc, Dover, N.H. 03820
12954	Dickson Electronics, Scottsdale, Ariz.
13327	Solitron Devices, Tappan, N.Y. 10983
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19644	LRC Electronics, Horseheads, N.Y.
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